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HYDROTHERMAL LEACHING OF IRON ORES OF THE LAKE SUPERIOR TYPE—A MODIFIED THEORY.

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INTRODUCTION.

A HYPOTHESIS for the oxidation and leaching of iron formations chiefly by hot magmatic waters was advanced by the author ten years and six years ago, respectively.[1] The many discussions favorable and unfavorable which followed helped him greatly in formulating the modified hypothesis presented in these pages. The recently published, highly detailed investigations by Allen and Day[2] on the hot springs of Yellowstone Park provided the writer with excellent data that makes it possible to elevate the hypothesis to the rank of a theory, it is believed. It differs from the old ideas chiefly in laying more stress on heated *meteoric* waters than was done before, especially in the case of the soft Mesabi ores to which it will be specifically applied in the following pages. No modification of the original hydrothermal hypothesis would have been necessary for the hard Vermilion and Marquette ores in which replacement of quartz by hematite has

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[1] Gruner, J. W.: The Soudan formation and a new suggestion as to the origin of the Vermilon iron ores. ECON. GEOL., vol 21, pp. 629–644, 1926.

Gruner, J. W.: Hydrothermal oxidation and leaching experiments; their bearing on the origin of Lake Superior hematite-limonite ores. ECON. GEOL., vol. 25, pp. 697–719; 837–867, 1930.

Gruner, J. W.: Additional notes on secondary concentration of Lake Superior iron ores. ECON. GEOL., vol. 27, pp. 189–205, 1932.

[2] Allen, E. T., and Day, A. L.: Hot springs of the Yellowstone National Park. Carnegie Inst. of Washington, Pub. 466, 1935.

been an important process. But here, too, heated meteoric waters probably have been a significant factor in the leaching of silica. Lack of space does not permit a review of the papers of 1930 and 1932, with which the student will need to be acquainted to some degree in order to follow this discussion closely.

FACTORS OPPOSED TO WEATHERING PROCESSES.

Restatement of factors which led to the abandonment of the weathering hypothesis for the Mesabi ores.[3]

1. Large ore bodies extend to a known depth of 905 feet.
2. No change in the quality and physical condition of the ore is recognizable with depth.
3. Solution of quartz and not only of silicates on a vast scale.
4. Complete oxidation of ferrous iron and especially of magnetite to martite.
5. Complete lack of leaching of silica unless accompanied or preceded by oxidation.
6. No apparent leaching of silica today as shown by mine water and other water analyses.
7. Probability that cold meteoric waters entering the iron formation were already saturated with respect to silica (for that temperature) due to previous contact with silicates in the soil and in other formations.
8. Probability that the leaching of the ore bodies was practically completed in pre-Cambrian time.
9. Lack of synclinal structures under the ore bodies to guide the flow of meteoric waters.

[3] ECON. GEOL., vol. 25, pp. 850–858. ECON. GEOL., vol. 27, p. 203.

The geology of the Mesabi range is simple. The Upper Huronian Biwabik iron formation overlies Pokegama quartzite and underlies Virginia slate conformably. The dip of the formations is southward and averages about 10 degrees. Taconite which makes up the iron formation, is a banded ferruginous quartz and greenalite rock containing some slaty phases of which the "intermediate slate (paintrock)" is the most prominent. The most common iron mineral in the taconite is fine-grained magnetite. Next in abundance are greenalite, siderite and hematite. The ore bodies are troughs in shape. The troughs are due to slumping of the ore layers after leaching out of the silica.

10. Absence of important impervious layers in the iron formation under which artesian waters might have circulated.

11. The axes of elongation of ore bodies in the majority of cases are not in positions which would be expected if the leaching solutions had flowed down the dip of the formation.

12. Many ore bodies do not extend up the dip to the surface but appear to be cut off. If circulation had followed the bedding planes down the dip the portions of the formation between the surface and the ore bodies should have been leached first.

13. Steep and sharp walls of many ore bodies indicate rapid circulation in well defined zones.

14. Notwithstanding the lack of structures controlling cold ground water circulation, ore bodies are confined to a limited number of areas. The iron formation between these places is unattacked.

15. The slumping of the ore bodies from wall to wall for as much as 250 ft. vertically was caused by leaching of silica from the bottom of ore bodies *upward*. If leaching had started at the top the porous ores could have been eroded as rapidly as they formed. Besides, there would have been no reason why the groundwaters should have descended from a porous zone into a dense unleached rock with their load of silica. On the other hand, if leaching started from below, the deposition of silica as sinter at the surface would have protected the ore bodies from erosion for extended periods.

16. During the leaching period the then existing erosion surface was at least 150 to 250 feet higher in the neighborhood of the large ore bodies than it is today (Fig. 2). This is proved by the fact that the top layers of the large ore bodies have slumped that distance. This also means that at least some of the ore bodies were covered partially by Virginia slate when leaching occurred. As a matter of fact, patches of this highly altered and bleached slate have been found on top of at least two ore bodies.

17. Existence of large Keweenawan intrusives under the iron formation as proved by diabase intrusions in the iron formation at least as far west as Keewatin. West of this town leaching is

incomplete and "wash ores" are the result, indicating that the solutions were less potent, in other words, not as hot as farther east.

18. Lack of ore bodies on the East Mesabi and Gunflint ranges where the intrusives (Duluth gabbro) came to rest above the iron formation making *any* kind of circulation impossible.

19. Occurrence of very large magnetite crystals in cavities in conglomerate ore between Mountain Iron and Kinney.[4]

FACTORS OPPOSED TO HYDROTHERMAL LEACHING.

Factors which seem to argue against leaching by magmatic waters.

(*a*) Magmatic waters should have been nearly saturated with silica when they entered the iron formations unless they passed through the gaseous phase on the way up and condensed on reaching the iron formation, a change conceivable if the temperature on mingling with ground water dropped sufficiently for the existing pressure.

(*b*) Some ore bodies bottom in the iron formation some distance above the Pokegama quartzite. Apparently there is not much leaching under them. If the magmatic emanations rose essentially in a vertical direction this lack of leaching may be explained by the existence of the emanations in the gaseous state before reaching the site of the ore body.

(*c*) Minerals commonly thought to be associated with magmatic waters are rare. However, as pointed out previously [5] on account of the simple composition of the iron formations interaction with them could not have produced very complex minerals, even if the temperatures had exceeded 200° C on the Mesabi range.

(*d*) Limonite (goethite) is present in relatively large amounts. It is an alteration product of the iron silicates and siderite. There has been considerable discussion as to the upper limit of

[4] Gruner, J. W.: Magnetite cementing certain ore conglomerates of the Mesabi Range. ECON. GEOL., vol. 29, pp. 757–760, 1934.

[5] ECON. GEOL., vol. 27, p. 196, 1932.

stability of goethite [6] which is supposed to be at about 140° C. Goethite has been reported, however, lately from bore-holes in the Yellowstone Park geyser basins [7] at depths to almost 400 feet. The measured temperature where the goethite was found was as high as 175° to 180° C. It is conceivable that it even exists at somewhat higher temperatures since field observations were not carried beyond this temperature. The petrographic descriptions by Fenner suggest to the writer that the temperature of *formation* of this goethite may have been higher than the measured temperature. Be this as it may, this occurrence proves that goethite (limonite) exists at temperatures close to 180° C.

HEATING OF METEORIC WATERS BY MAGMATIC EMANATIONS.

The belief that water issuing from hot springs is heated by igneous intrusions, chiefly by coming in contact with the hot rocks, is of long standing. It has been applied almost universally to geyser waters. More recently geologists have also given credit to hot gases escaping from a magma as media for heating meteoric ground waters. Lately Allen and Day [8] have come to the conclusion that the large quantities of geyser water in Yellowstone Park do not receive their heat from any igneous rock with which they are in direct contact. It is inconceivable that igneous rock, which is a poor conductor, could lose such enormous quantities of heat as rapidly as is required by the amounts of run-off observed and over a period of many thousands of years. The chilled contacts would soon become good heat insulators. Therefore, the heat must be supplied by some other means not subject to these limitations. Hot emanations rising from a deeper source, chiefly as gases, seem to be ideal for these processes. They possess high mobility, great heat capacity, and are of a large enough order of magnitude. Steam would be the chief con-

[6] Tunell, G., and Posnjak, E.: The stability relations of goethite and hematite. ECON. GEOL., vol. 26, p. 337, 1931.

Gruner, J. W.: ECON. GEOL., vol. 26, p. 442, 1931.

[7] Fenner, C. N.: Bore-hole investigations in Yellowstone Park. Jour. Geol., vol. 44, no. 2, part 2, p. 237 and 270, 1936.

[8] *Op. cit.*, p. 214.

stituent. It would, of course, condense if brought in contact with sufficient amounts of meteoric water. Even at this late stage of activity in Yellowstone Park, heat sufficient to melt three tons of ice every second is imparted to about 109 cu. ft. of water per second, according to Allen and Day.[9] This water carries away in solution about 390 tons of material in 24 hours according to the same authors,[10] of which a considerable part is SiO_2.

Oxidation and Leaching of Iron Ores.

It is a relatively simple matter to apply the above mentioned facts and ideas to the oxidation and leaching of the Lake Superior iron ores and especially to those of the Mesabi range where the magmatic water hypothesis had met with the objections enumerated under points *a* to *d*. The iron formations are much jointed and fractured due to their brittleness, permitting easy access of groundwaters along these openings. In some areas where basic intrusions of Keweenawan age approached the Biwabik formation from below more closely than in others, this fracturing may have been even more pronounced. It may be assumed that groundwater saturated the iron formation. It has been suggested by Leith[11] that the Lake Superior region was semi-arid, a very low water table presumably being necessary for oxidation and leaching to 3000 and 4000 feet depth in a "mountainous region." The relative attitudes of ore bodies and surrounding structural features have remained essentially unchanged since the beginning of formation of the ore bodies. It is, therefore, difficult to expect any aid from such assumed conditions for the hypothesis of cold water circulation either with regard to quantity or depth. It is much more likely that there was plenty of water available for leaching of silica at the same time as oxidation occurred, for field study has shown these two processes most intimately connected. They began to operate on a grand scale when hot gaseous emanations broke through and in their upward

[9] *Op. cit.*, p. 55.

[10] *Op. cit.*, p. 128.

[11] Leith, C. K.: Secondary concentration of Lake Superior iron ores. ECON. GEOL., vol. 26, p. 286, 1931.

rush heated and deflected the ground waters toward the surface (Fig. 1). The path of least resistance was upward. Even if the ground water had lacked any appreciable head due to topographic conditions it could not have "backed up" on account of greater friction laterally.

It is, of course, impossible to estimate the amount of magmatic water of the emanations that condensed and mingled with the meteoric water. The amount of silica that was carried in solution may have been of similar magnitude as in Yellowstone Park where some waters contain as much as 800 parts per million. This silica was largely deposited on the surface. Besides protecting the underlying ore from erosion temporarily, this capping had another function. It frequently sealed off early channels and caused spreading of the leaching laterally and up and down the dip (Figs. 1 and 2). As the water and gases were expelled, ground water would enter laterally and down the dip. This could occur, of course at *any* horizon in the iron formation depending upon local conditions. Such behavior explains the sudden ending of ore bodies in the taconite either laterally or vertically at depth. These points are really the places where the meteoric waters first came in contact with the hot emanations and acquired their leaching power. Genetically they are the beginnings, not the ends, of the ore bodies.[12] This interpretation

[12] On the Gogebic range where in places as many as six ore bodies occur at six different elevations one above the other, the new theory is able to explain such stacking almost perfectly. On the Cuyuna range known ore bodies reach to a depth of almost 900 ft. They follow steeply dipping beds downward and bottom in iron formation commonly. This at first rather puzzling fact finds its explanation now. The emanations and meteoric waters met at these depths and rose together. The "hanging ore bodies" of the Marquette and Menominee district (ECON. GEOL., vol. 25, p. 841 and 847, 1930) find a logical interpretation as to their attitude for the first time. The positions of the soft ores of the Marquette range are also readily explained.

One is not dependent, therefore, on ancient erosion surfaces in the iron formations as Mr. Stephen Royce believes (ECON. GEOL., vol. 27, pp. 487–491, 1932 and ECON. GEOL., vol. 28, p. 293, 1933). He makes it a point to show that in the Brotherton-Sunday Lake properties of the Gogebic range a Keweenawan erosion surface reached the iron formation and that an ore body was formed at that place due to surface oxidation and leaching. Iron ore pebble conglomerate lies between the ore and the

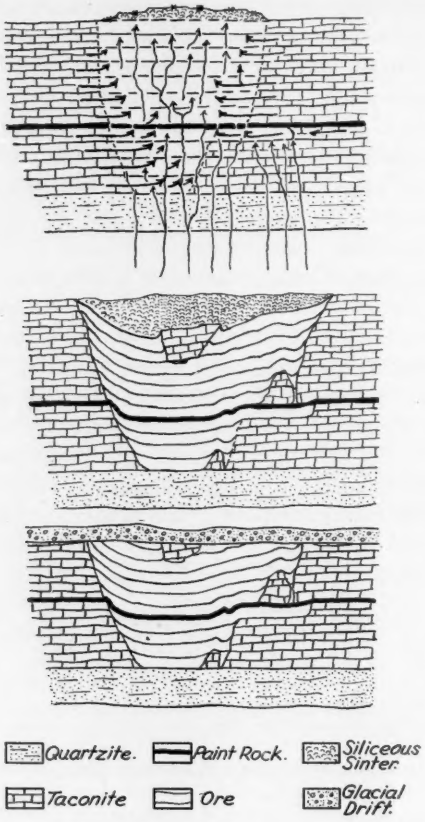

FIG. 1. First stage in the development of Mesabi ore body. Rising emanations mingle with meteoric waters entering at different horizons of iron formation.

FIG. 2. Final stage of leaching. Due to the capping of sinter the ore body has spread laterally.

FIG. 3. Ore body after erosion of capping and deposition of glacial drift. The vertical sections are parallel to the strike of the formation.

also furnishes a ready answer to the common question: "Where did the silica go to?"

The axes of the ore bodies followed those fissures which gave egress to the largest quantities of solution. The underlying quartzite was less jointed. As it contained no ferrous minerals (as did the iron formation) which on oxidation disintegrated the rock and facilitated circulation, it was attacked relatively little. Where the temperature and emanations decreased before leaching was fairly complete (or were lower to begin with), wash ores high in loose quartz grains resulted. No cold water hypothesis can explain why leaching activity shows a *gradual* decline from Hibbing westward for 40 miles. A fading of igneous activity westward offers an easy explanation, on the other hand. The occurrence of these "sugary" quartz phases in the iron ores which can be removed by washing are not confined to the Mesabi range but seem to occur in practically all ores of the Lake Superior type though in quite different proportions. They have even been described lately from the Minas Geraes ores by Sanders [13] where they occur in enormous quantities.

Keweenawan sediments. He fails to mention that the ore body is intimately associated with a diabase dike upon which it is found. In this respect (and probably therefore in origin) it is like the great majority of the Gogebic ore bodies which were *not* formed on an ancient erosion surface between the Tyler slate and iron formation. The conglomerate was formed when later erosion cut into the ore layers.

Attention is called once more to the fact that intrusive activity immediately preceded the formation of ore bodies and as far as known lasted until after the ore bodies were completed. This applies especially to the Gogebic and Marquette ranges. One does not receive that impression for the Marquette range, however, when reading the guide book of the International Geological Congress (Guidebook 27, Lake Superior Region, 1933, p. 16). C. O. Swanson does not mention there the earlier intrusives, which arrived before Upper Huronian time in the Negaunee iron formation according to Van Hise, Bailey and Leith. The writer thinks them responsible for the hard ores, that is the heat which came from the larger masses of the same magma. The soft ores were caused by the heat from the Keweenawan magmas. This statement is a departure from his earlier ideas (ECON. GEOL., vol. 25, p. 865, 1930) that all the Marquette ores might have been of one period of concentration.

[13] Sanders, B. H.: Iron ores at Itabira, Brazil. Inst. Min. and Met., Bull. 346, July, 1933.

CONCLUSIONS.

A modified theory of hydrothermal oxidation and leaching of the Lake Superior iron ores, especially of the Mesabi ores, is advanced. It is proposed that the chief source of the hot waters was meteoric. The waters mingled with gaseous emanations that rose from large intrusives. Ordinarily nearly stagnant, these ground waters when heated became active solvents of silica. They were deflected upward and with the emanations issued at the surface depositing their silica load as sinter on the ore. The sinters formed a temporary protection against erosion of the soft ores. The emanations probably were largely superheated steam and as such were able to heat large quantities of meteoric water by the heat of condensation alone. Expulsion of hot water and influx of new ground water from all sides was a process that continued as long as emanations stimulated circulation. The action may be compared to that taking place in the hot springs region of Yellowstone Park today. Close study shows that practically all former difficulties encountered in adhering strictly either to the weathering or the magmatic water hypothesis disappear. The new theory is applicable to all iron ores of the Lake Superior type. The chief differences are probably only in type, temperature, and quantities of the emanations. Variations in compositions of the formations and their attitudes with respect to dikes, faults and more or less impervious beds could readily account for some of the differences that one sees in the field. Although the subject is a very tempting one it is beyond the scope of this paper to apply the theory to pre-Cambrian iron ores of other continents.

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GEOLOGY AND PARAGENESIS OF THE GOLD ORES OF THE HOWEY MINE, RED LAKE, ONTARIO.

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INTRODUCTION.

RED LAKE lies in the Patricia portion of the Kenora District, Ontario, about forty miles northwest of Lac Suel (Goldpines). The Howey mine is located on the southwest shore of the southeast bay of Red Lake about one half mile west of Lornow Lake.

In 1893 the late D. B. Dowling visited the territory between the English and Berens Rivers; his report [1] noted the sedimentary rocks occurring around Red Lake. In 1922 and 1923 the Ontario Department of Mines sent a field party to Red Lake under the direction of E. L. Bruce.[2] In 1926 a second party was sent into this area under the leadership of E. L. Bruce and J. E. Hawley,[3] which undertook a more detailed study of the district. During the period of this later study the Howey property was undergoing its early development. In October, 1934, E. L. Bruce and the staff of the Howey mine published a complete description [4] of the operation and management of the mine, a description of the ore-body and a résumé of the geology.

The author is greatly indebted to Mr. Edward Futterer, Resident Manager and the Engineering Staff of the Howey mine for their many courtesies. To Edson S. Bastin and Albert Johannsen of the Department of Geology, University of Chicago, the writer wishes to express his appreciation for their valuable advice and criticism, so generously given.

[1] Dowling, D. B.: Can. Geol. Surv., vol. 2, pt. F.

[2] Bruce, E. L.: Ont. Dept. Mines Ann. Rept., vol. 33, pt. 4, 1924.

[3] Bruce, E. L., and Hawley, J. E.: Ont. Dept. Mines Ann. Rept., vol. 36, pt. 3, 1927.

[4] Can. Mining Jour., Oct., 1934.

GENERAL GEOLOGY.

The rocks outcropping on the Howey property are predominately intermediate and basic lavas and associated pyroclastics of Keewatin age, intruded by a portion of the porphyry masses that are typical of the area. According to Wright,[5] the porphyry dikes have an *en échelon* arrangement to the north, and Bruce[6] states they are Post-Timiskaming (Algoman) in age. The strike of the main dike in the Howey mine is N. 63° E. and the dip about 80° S. It varies in width from 60 to 300 feet, the widest portion being east and west of the shaft and below the 1100 foot level. The lavas and porphyry dikes are traversed by diorite and so called "lamprophyre" dikes.

The ore body occurs in a dike rock described by Bruce[7] as quartz porphyry. In reality, however, it is a composite dike, consisting of at least three closely associated porphyry dikes of different ages. Two of them are known locally as "waxy porphyry" and "dark porphyry"—the author has termed the third "lighter tonalite porphyry."

Above the 1100 foot level the waxy porphyry is the predominating wall rock, darker tonalite porphyry increases below this depth. The lighter tonalite porphyry was positively identified only on the 1175 foot level.

Petrography of the Rocks on the Howey Property.

Bostonitic Andesite Porphyry or "Waxy Porphyry."—The bostonitic andesite porphyry is locally called "waxy porphyry" and is a fine-grained dike rock, megascopically light green in color and waxy in appearance. Thin sections show phenocrysts of sodic oligoclase. The rock has a bostonitic or haphazard texture and is composed of laths of plagioclase (sodic oligoclase) in a fine-grained groundmass of quartz, sodic oligoclase, accessory biotite (less than 1 per cent.) and magnetite. Sericite, carbonate, kaolin, chlorite and quartz are alteration products of the primary

[5] Wright, D. G. H.: The Red Lake gold area. Eng. Min. Jour., p. 18, July, 1926.
[6] Bruce, E. L., and Hawley, J. E.: *Op. cit.*, p. 3.
[7] Idem: pp. 31–32.

minerals. Pyrite, quartz, chlorite and carbonate have been secondarily introduced.

Specimens from different parts of the mine have undergone different degrees of alteration, in many cases resulting in a schistose-cataclastic texture with only traces of the earlier porphyritic-bostonitic texture.

Lighter Tonalite Porphyry.—The lighter tonalite porphyry is a fine to medium-grained dark rock. The plagioclase phenocrysts have undergone crushing and recrystallization and are partially altered to sericite, carbonate and kaolin. The schistose matrix consists of feldspar, quartz, biotite and magnetite now partially altered to white mica, carbonate, kaolin and chlorite. Pyrite, quartz and carbonate have been introduced by hydrothermal solutions. The biotite has been bleached, and the feldspars have undergone more sericitization and carbonatization than those of the andesite porphyry. The original composition of the rock was probably about 60 per cent. quarfeloids and 40 per cent. biotite. The rock is a tonalite porphyry and differs from the andesite porphyry in that the latter contains a larger percentage of quarfeloids and less biotite. The andesite porphyry is less altered and has larger phenocrysts than the lighter tonalite porphyry. Sodic oligoclase forms the phenocrysts in the former and oligoclase in the latter.

Darker Tonalite Porphyry or "Dark Porphyry."—The darker tonalite porphyry, locally called "dark porphyry," consists of elongated "eyes" of quartz in a matrix of biotite with smaller amounts of plagioclase. Apatite, magnetite, zircon, carbonate, white mica, chlorite and pyrite occur in smaller amounts. The original composition of the rock was probably 60 per cent. biotite and 40 per cent. quarfeloids. The feldspar has been altered to sericite and kaolin, the biotite to chlorite, and the magnetite largely altered to leucoxene. The rock is now a biotite schist and originally was probably a melatonalite or darker tonalite porphyry. It differs from the lighter tonalite porphyry not only in color but in being finer-grained, more schistose and in containing more biotite and less quarfeloids. There is also a more or less parallel

arrangement of the pyrite whereas in the lighter tonalite porphyry the pyrite grains are scattered heterogeneously through the rock. In addition, the lighter tonalite porphyry does not contain the elongated " eyes " so characteristic of the darker tonalite porphyry.

Biotite Schist or " Lamprophyre."—A fine-grained, black dike rock locally called " lamprophyre " transects the various porphyries and varies from stringers to dikes a few feet wide. It was originally composed almost entirely of biotite, now partially bleached, and a few scattered grains of quartz. Sericite, quartz and carbonate have been secondarily introduced. The rock differs from the dark porphyries in being finer-grained and in consisting almost entirely of biotite. It is not a lamprophyre since it does not contain feldspar or dark phenocrysts and consists almost entirely of biotite; therefore either " glimmerite," suggested by Larsen and Pardee,[8] or " biotitite," suggested by H. S. Washington,[9] is a more suitable term. It is so highly altered that it may well be called a biotite schist.

Diorite.—Diorite is a coarse-grained intrusive rock occurring as a single dike in greenstone near the porphyry dikes. In thin sections it is found to consist of the following minerals: amphibole 60.0 per cent., quartz 1.0 per cent., oligoclase 25.0 per cent., epidote 8.0 per cent., magnetite 3.0 per cent., carbonate 2.0 per cent. and biotite 1.0 per cent. Pyroxene, pyrite and titanite are accessories.

Andesite or " Greenstone."—A specimen of greenstone, procured near the mine, is composed of large phenocrysts of oligoclase partially altered to kaolin; amphibole partially altered to chlorite, in a fine-grained groundmass of chloritized biotite; apatite, titanite and magnetite are accessory minerals; carbonate, quartz and pyrite are secondarily introduced. Flow texture indicates the extrusive character. The rock was originally an andesite.

[8] Larsen, E. S., and Pardee, J. T.: The stock of alkaline rocks near Libby, Montana. Jour. Geol., vol. 37, p. 101, 1929.

[9] Washington, H. S.: The italite locality of Villa Senni. Am. Jour. Sci., vol. 14, pp. 187–189, 1927.

The Effect of the Porphyry Intrusion.—"Greenstone" specimens, procured about one half mile from the porphyry intrusion consist of chlorite, oligoclase and amphibole. Changes in the composition of the "greenstone" were observed at the immediate contact with the porphyry, where the country rock is composed of chlorite, sericite, oligoclase, quartz and biotite.

It is difficult to separate the effect of the porphyry intrusions from the later hydrothermal alterations. Chlorite is developed in the lavas of the whole area. Sericite is known to have been developed in the porphyry by the hydrothermal solutions; therefore it is probable that part of the sericite in the greenstone is derived from this source. The change in feldspar to a more sodic variety is probably due to the intrusion of the andesite porphyry, which contains sodic oligoclase. The development of biotite may be due to the alteration of the amphibole or to introduction during the intrusion of the tonalite porphyries, since the latter introduced biotite into the earlier andesite porphyry.

SEQUENCE OF EVENTS LEADING UP TO ORE DEPOSITION.

1. *Deposition of Keewatin lavas and pyroclastics on an unidentified terrain.*

2. *Intrusion of andesite porphyry into Keewatin lavas.*

3. *Fracturing of andesite porphyry and subsequent filling of the fractures by quartz and massive pyrite.* Proof of this fracturing was observed on many mine levels where quartz veins, traversing andesite porphyry, are sharply terminated by tonalite porphyry.

Additional evidence of the earlier age of the andesite porphyry was found on the 750-foot level. Here, at the contact between the andesite porphyry and darker tonalite porphyry, small apophyses of the latter are injected into the former. Similar occurrences were observed on other levels. On the 1175-foot level there is an andesite-lighter tonalite porphyry contact showing apophyses of the latter injected into the former.

Thin sections of a sharp boundary between the andesite and darker tonalite porphyries show the latter to be exceedingly fine-

grained at the contact (Fig. 2), becoming coarser-grained a short distance from it. In addition, the darker tonalite porphyry bulges around large feldspar phenocrysts projecting from the andesite porphyry. The andesite porphyry at the boundary has undergone sericitization and the introduction of a small amount of biotite, but shows no marked diminution of grain size.

4. *Intrusion of the lighter tonalite porphyry into the andesite porphyry.* As pointed out in the preceding discussion, apophyses of this rock occur in the andesite porphyry.

5. *Intrusion of darker tonalite porphyry.* As previously stated, apophyses of the darker tonalite porphyry transect the andesite porphyry and, in addition, dikes of the dark rock cut across large andesite porphyry masses.

Thin sections of the lighter-darker tonalite porphyry boundary show a chilled darker tonalite porphyry with a very fine grain at the contact, becoming coarser-grained at a short distance from it. In addition, the former has undergone more alteration than the latter rock. Similar evidence is found in thin sections of the andesite-darker tonalite porphyry contact proving definitely the later age of the darker tonalite porphyry. Except in a few cases the contacts between the various porphyries are very sharp.

6. *Fracturing of all the porphyry dikes and subsequent filling of the fractures by quartz.*—Before the "lamprophyric" intrusion there must have occurred a period of intense fracturing and brecciation since the porphyries all appear more highly shattered than the later "lamprophyres."

7. *Intrusion of "lamprophyre" dikes which transact the various porphyries.*

8. *Period of faulting; quartz and pyrite crystallizing in the fractures.* In the roof of the 750 east level a "lamprophyre" dike has been cut off by a fault, the break now occupied by a barren quartz vein 18 inches in width. Other instances of a similar nature were observed in many places.

9. *Another period of fracturing, largely of the tensional type; the fractures were subsequently filled by the ore minerals.*

ORE DEPOSIT.

The Ore Body.

The Howey ore body (Fig. 1) is a lode deposit, approximately 1000 feet long and the width increasing from 50 feet at the sur-

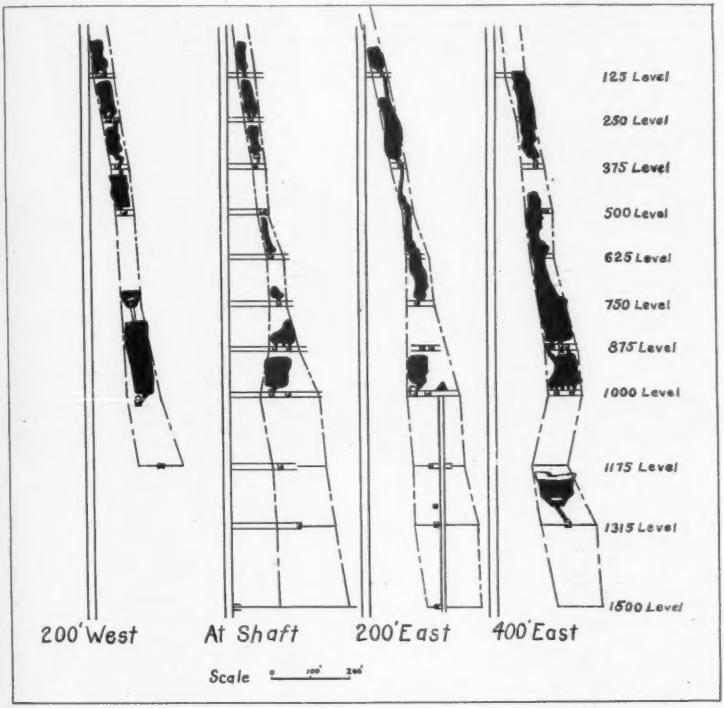
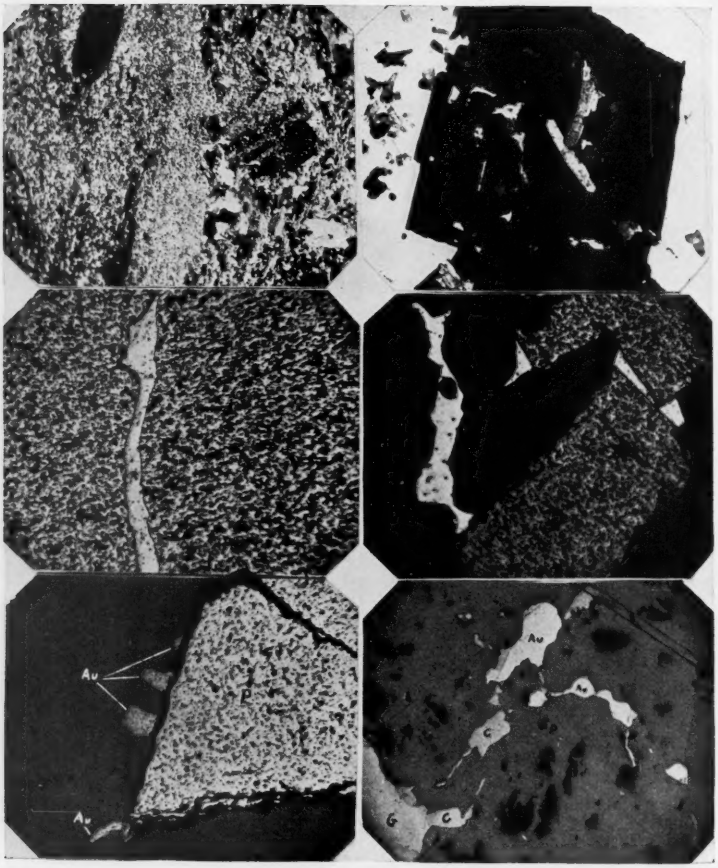


FIG. 1. Vertical cross-section of the Howey gold mine showing boundaries of the porphyry masses (broken lines) and the mined ore (black).

face to 175 feet on the 1500-foot level. It is dike-like in form, forming a portion of one of the porphyry masses that intrude the greenstone of the area, and consisting of a mass of lenticular



FIGS. 2–7.

sheet-like quartz-tourmaline-carbonate veins. Those bearing gold are mostly less than 6 inches wide.

The vein system appears complex and the author's findings are in accordance with those of Bruce and Hawley [10] who state that

> The strike of most of the veins is at an angle of approximately 20° S. of that of the main porphyry mass, which trends at N. 63° E. Some veins strike with the porphyry, others lie at about N. 17° W. and minor ones have various alignments. The most prominent fractures lie nearly parallel with the direction of the porphyry. In general, the veins are lenticular sheets filling fractures, nearly vertical or dipping with the porphyry steeply south. . . . The shearing of the relatively brittle porphyry mass caused the fractures of both tensional and shear origin. Into these, principally the former type, came quartz and various sulphides. . . .

The porphyry mass, in which the ore body is located, is a composite dike and was formed, preceding the ore deposition, by three separate intrusions along the same zone of weakness. The localization of the ore body is attributed to the greater abundance of "waxy porphyry" and earlier quartz veins, which are more easily and more cleanly fractured than the "greenstone," "lamprophyre" and darker porphyries. It is therefore the zone of greatest weakness and most severe fracturing.

The average ore value is $2.75 per ton.

[10] *Op. cit.*: Ont. Dept. Mines Ann. Rept., vol. 36, pt. 3, pp. 59–61.

FIG. 2. Contact of bostonitic andesite porphyry (waxy porphyry) and darker tonalite porphyry (dark porphyry). The former is coarser grained and contains a feldspar phenocryst while the latter has a chilled contact and is composed of small sericite grains. ×-nicols. × 40.

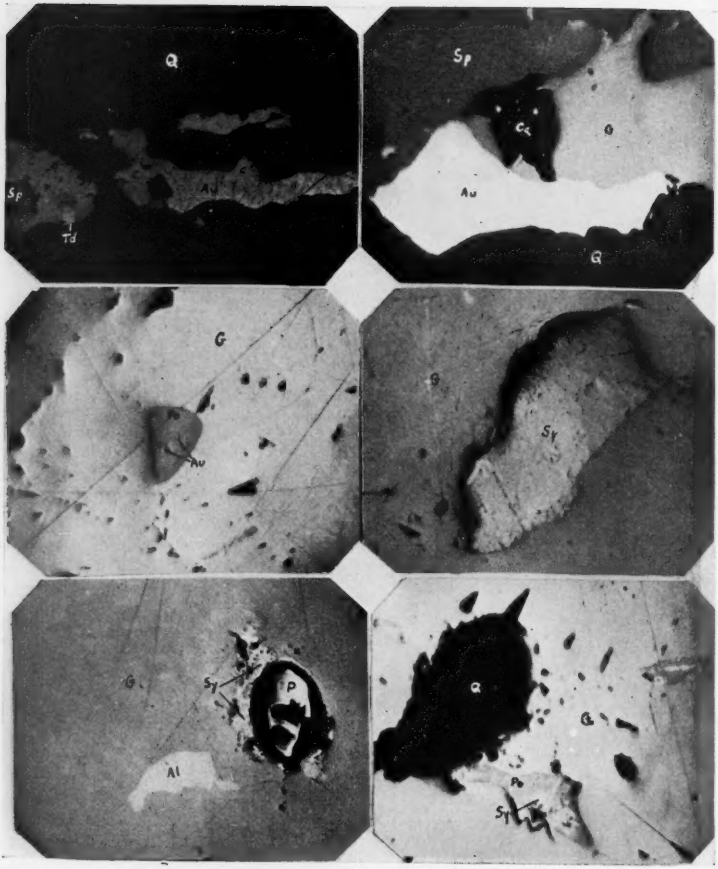
FIG. 3. Automorphic tourmaline laths (gray) in pyrite cube (black). Quartz is white. × 70.

FIG. 4. Free gold (light gray) replacing and filling a fracture in pyrite (mottled). × 80.

FIG. 5. Interstitial free gold (white) and pyrite cubes (mottled) in quartz (black). × 63.

FIG. 6. Free gold (Au) occurring at contact of pyrite (P) and quartz (dark gray) and replacing the latter. × 63.

FIG. 7. Gold (Au) and chalcopyrite (C) as blebs in sphalerite (Sp). Chalcopyrite intergrown with galena (G). × 100.



FIGS. 8–13.

Mineralogy.

This subject includes both a description of the occurrence and appearance of the metallic and non-metallic minerals that constitute the ores. The metallic minerals were definitely identified by their physical and optical properties and their reaction to various etching reagents as described by Short[11] and also by microchemical tests as outlined by Chamot and Mason.[12]

Pyrite (Figs. 3, 4, 5, 6), one of the earliest of the ore minerals to crystallize, is the most abundant metallic mineral in the ores. It is also found in all rocks associated with the ores. Its age in the wall rocks can not be ascertained with certainty. It is known to have accompanied quartz at each period of fracturing and subsequent fracture-filling; a possible exception is that which followed the introduction of gold and its associated minerals.

Free gold (Figs. 4, 5, 6, 7, 8, 9) occurs generally in a finely divided state, and is megascopically visible in only four hand specimens. Under the microscope it was identified in four fifths of all specimens examined. In polished section the color varies from golden to pale yellow. Van der Veen[13] states that the pale color of certain free gold is due to the silver it contains in

[11] Short, M. N.: Microscopic determination of the ore minerals. U. S. Geol. Surv. Bull. 825, 1931.

[12] Chamot and Mason: Handbook of Chemical Microscopy. John Wiley and Sons, New York, vol. 2, 1931.

[13] Van der Veen, R. W.: Mineragraphy and ore deposition. The Hague, p. 106, 1925.

FIG. 8. Free gold (Au) and chalcopyrite (C) forming a veinlet in quartz (Q). Blebs of tetradymite (Td) and sphalerite (Sp) in chalcopyrite. × 80.

FIG. 9. Free gold (Au) intergrown with carbonate (Ca), galena (G), sphalerite (Sp) and quartz (Q). × 100.

FIG. 10. Polybasite (Po), containing small free gold (Au) inclusions in galena (G). × 100.

FIG. 11. Sylvanite (Sy) inclusion in galena (G). × 100.

FIG. 12. Altaite (Al), sylvanite (Sy) and pyrite (P) in galena (G). × 100.

FIG. 13. Polybasite (Po) intergrown with sylvanite (Sy) and forming inclusions in galena (G). Non-metallic is quartz (Q). × 110.

solid solution; this is verified by the occurrence of the pale yellow type as blebs in polybasite (Fig. 10). Microchemical tests show that the amount of silver present is insufficient to form electrum. The difference in color and therefore in composition can be correlated with difference in age; the golden yellow type is older and the pale yellow is younger.

Sylvanite, tetradymite, aikinite, polybasite and free gold are closely associated, the latter commonly occurring as an inclusion in the others. Carbonate is the predominant contemporaneous gangue mineral, although in many cases quartz contains isolated blebs of free gold.

Chalcopyrite (Figs. 7, 8) is indicative of high gold values, and is generally associated with galena and sphalerite, but specimens from the 500-foot stope consist almost entirely of chalcopyrite, free gold, pyrite, tetradymite, aikinite, galenobismuthinite and a small amount of sphalerite.

Galena (Figs. 9, 10, 11, 12, 13) is also considered indicative of high gold values and is mostly associated with the tellurides, sphalerite, chalcopyrite and free gold. In hand specimens it is seen as irregular masses in fractured quartz, but thin sections and polished surfaces show that it also occurs with tourmaline. If veinlets of tourmaline are traced, they eventually pass into quartz-carbonate veinlets containing galena, chalcopyrite and sphalerite.

Sphalerite (Fig. 7) is one of the most abundant of the metallic minerals and, in mining, is considered an indication of high gold values. In the Howey ore body it is of the lighter-colored resinous type, in spite of the fact that it was deposited in the presence of iron under hypothermal conditions. Polished sections show that it varies in hardness, in different crystal directions, which produces an appearance similar to the polysynthetic twinning in feldspar. Quartz is the predominant contemporaneous gangue mineral.

Cubanite (Fig. 14) occurs as long laths in specimens of chalcopyrite from the 1300-foot stope.

Pyrrhotite occurs almost exclusively in sphalerite but occasionally in chalcopyrite.

Arsenopyrite is found in specimens from all parts of the mine, but is especially abundant in those from the east 750-foot level. It commonly occurs along sphalerite-quartz contacts, showing automorphic contacts against quartz and mutual boundaries with sphalerite.

Löllingite occurs along quartz-sphalerite contacts similar to arsenopyrite.

Tetrahedrite occurs as automorphic inclusions or as irregular-shaped interstitial masses in sphalerite.

Polybasite (Figs. 10, 13) occurs almost entirely as inclusions in galena, which are generally composed of an intergrowth with either sylvanite or tetradymite. Inclusions of polybasite commonly contain blebs of the lighter-colored silver-bearing free gold. The shape of the inclusions vary from lath-like to irregular.

Sylvanite (Figs. 11, 13) is invariably associated with galena, generally possesses a lath-like or irregular form, and commonly occurs in galena inclusions in sphalerite or as lath-shaped grains that project from galena into sphalerite. It is commonly intergrown with a small amount of chalcopyrite, free gold, polybasite or tetradymite as an inclusion in galena.

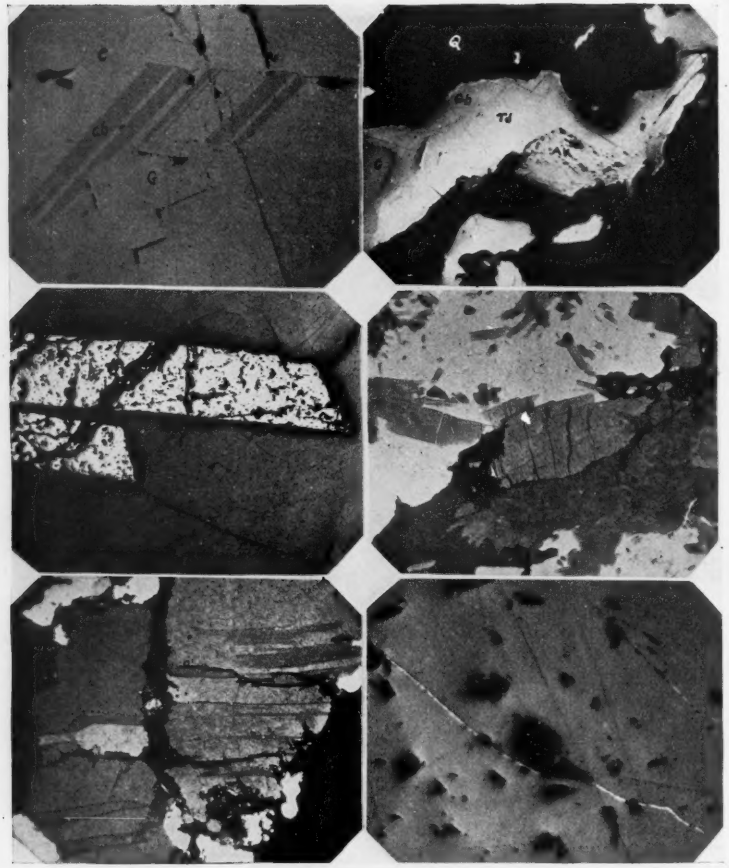
Altaite (Fig. 12) occurs only in galena where it is found as small irregular-shaped masses, rarely intergrown with the other tellurides or polybasite and is closely associated with free gold.

Tetradymite (Fig. 15), intergrown with galenobismuthinite, aikinite, chalcopyrite and free gold, is characteristic of ore from the 500-foot stope. It commonly occurs in galena as lath-shaped inclusions where it is intergrown with polybasite or sylvanite and closely associated with free gold.

Galenobismuthinite (Fig. 15) is almost invariably intergrown with tetradymite, aikinite, chalcopyrite and free gold.

Aikinite (Fig. 15) is intimately intergrown with galenobismuthinite, tetradymite, chalcopyrite and free gold.

Ilmenite occurs as thin platy, dark steel-gray crystals in a specimen from the 1300-foot stope. Specularite is the only metallic mineral associated with it. It is embedded in ankerite,



FIGS. 14–19.

which is the most abundant non-metallic mineral occurring in the later stages of mineralization. (Fig. 16.)

Specularite occurs as platy, dark steel-gray inclusions in ilmenite or intergrown with carbonate forming small veinlets in ilmenite. It is only found associated with ilmenite and carbonate.

Rutile occurs as thin, dark metallic needles in ankerite. The only other minerals found associated with it are small amounts of quartz and muscovite. Its occurrence is similar to that of ilmenite and specularite.

Tourmaline (Figs. 3, 17) occurs as isolated, automorphic, dark bluish-gray prismatic grains or as large aggregates of intergrown smaller grains. In the Howey mine it is indicative of pay ore, and narrow veinlets consisting of solid tourmaline, if followed along the walls of the mine-workings, eventually pass into quartz and carbonate veinlets containing ore. Tourmaline was never observed replacing the wall rocks. Its most characteristic occurrence is at the outer edge of the veins where it forms knife-like boundaries between vein and country rock. The center of these veins consists of quartz, oligoclase, carbonate, white mica and the metallic minerals. Their dip varies from vertical to horizontal. They cut all wall rocks alike from the earlier barren quartz veins and highly silicified porphyry to lamprophyre dikes, but are especially abundant in the andesite porphyry.

Quartz developed as fracture-filling at various times during the early geologic history of this area, but the present discussion is concerned only with that part which crystallized from the ore-bearing solutions. It is the most abundant gangue mineral, and occurs in two generations. The later one fills fractures in the

FIG. 14. Cubanite (Cb) laths in chalcopyrite (C) and projecting to chalcopyrite-galena (G) contact. × 85.

FIG. 15. Aikinite (Ak), tetradymite (Td), galenobismuthinite (Gb) and chalcopyrite (C) in quartz (Q). × 80.

FIG. 16. Ilmenite laths (white) in carbonate (dark gray). × 40.

FIG. 17. Ore minerals (black) filling fractures in tourmaline (darker gray) and also interstitial in tourmaline. Quartz is lighter gray. × 45.

FIG. 18. Ore minerals (black) filling fractures in vein feldspar (gray). Quartz is white. ×-nicols. × 20.

FIG. 19. Pyrite (white) veinlet in sphalerite (dark gray). × 108.

main metallic minerals and early quartz, tourmaline and early carbonate and is contemporaneous with later carbonate, ilmenite, specularite and rutile. The earlier generation, however, is more closely associated with the crystallization of the main ore-bearing minerals. In thin sections it is characterized by a comb-structure, mortar texture, sutured contacts between grains, undulatory extinction, and sharp contacts with the wall rocks. Therefore it is a fracture-filling and crystallized under stress, so intense that the contacts of many grains were granulated. The secondary quartz in the wall rocks is believed to have been derived from the breaking down of the silicate minerals in the wall rocks and from earlier siliceous solutions.

Quartz contains large areas of metallic minerals joined by small sulphide stringers, which are believed to have formed by their expulsion from the former as it crystallized, and therefore the sulphides were contained in the residual solutions and their crystallization was controlled by the crystal boundaries of quartz.

Oligoclase (Fig. 18), that occurs in the ore-bearing veins, is of the more sodic type. Quartz and oligoclase started crystallizing at the same time, but the former continued longer than the latter.

Carbonate occurs in two generations in the ore-bearing veins, one before and the other following the second period of fracturing. The later generation, which consists of predominant ankerite with small amounts of calcite, fills fractures that transect main ore-bearing veins. It is accompanied by small amounts of quartz, muscovite, ilmenite, specularite and rutile. The earlier generation consists of predominant calcite and a small amount of ankerite. Carbonate, like the metallic minerals, was expelled from the quartz-bearing solutions as the latter crystallized and therefore its crystallization was generally controlled by the crystal boundaries of quartz. As crystallization of the ore minerals progressed the amount of carbonate relative to quartz increased so that it became the main gangue mineral toward the end of the period of mineralization. The composition also changed from one high in calcium to one conspicuous for its magnesium and iron content.

White mica includes the shredded form generally called sericite, which is intergrown with the main ore minerals and books of muscovite associated with ankerite and ilmenite. The muscovite occurs along the walls of the ankerite veins, but the sericite is intergrown with the ore minerals that fill fractures in oligoclase or occurs along the crystal boundaries of quartz. Except for the fact that it is not intergrown with tourmaline and oligoclase, white mica is practically the same age as carbonate, sericite occurring with calcite and muscovite with ankerite. With the exception of chloritized biotite, it is the least abundant of the gangue minerals.

Chloritized biotite was only found in a few thin sections and is intergrown with chalcopyrite and galena as a fracture-filling in oligoclase.

Hydrothermal Alteration.

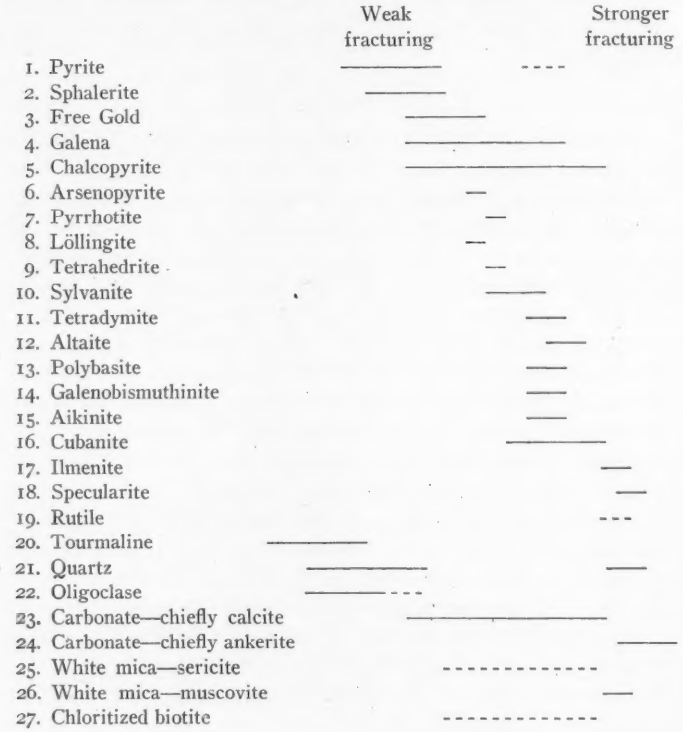
Quartz, sericite, carbonate and pyrite have been secondarily developed in the wall rocks. Part of the secondary quartz and carbonate was undoubtedly produced by the breaking down of the feldspars, by the fracture-filling solutions of an earlier period not accompanied by ore formation. This is proven by the more or less gradational contacts between large barren quartz veins, which are older than the ore-bearing veins, and the wall rocks. Sericite (or white mica), which is abundantly developed in all the wall rocks, has been produced by the disintegration of feldspar and also by the bleaching of biotite. It is believed that part of it can be attributed to the ore-bearing solutions. Pyrite occurs most abundantly in the older barren quartz veins, which are believed to be the source of most of the pyrite in the wall rocks.

Thin sections of ore-bearing tourmaline-quartz and quartz-carbonate veins show conclusively that there has been only a small amount of replacement of the bordering wall rocks because the contacts are sharp and straight and also show no marked increase in the quantity of the secondary constituents in the wall rocks adjoining the ore-bearing vein. In addition, thin sections of solid sphalerite veinlets have sharp straight contacts and show no replacement of the wall rocks.

CONCLUSIONS ON PARAGENESIS OF THE ORES.

Paragenesis Table.

The paragenetic sequence is broken into three stages by two episodes of fracturing. The first and second stages are separated by an episode of very weak fracturing which in thin and polished sections, is represented by small fractures in tourmaline (Fig. 17), quartz, oligoclase (Fig. 18) and pyrite (Fig. 4) that are filled by the later metallic and gangue minerals. The second and third periods are separated by an episode of stronger fracturing that is observed in hand specimens where ankerite-quartz veins cut



tourmaline-quartz veins. Small fractures in galena, filled with carbonate, chalcopyrite and cubanite and small fractures in sphalerite filled with pyrite (Fig. 19), may have formed at this time. The second period of mineralization is the most important because it includes all the valuable ore minerals.

Discussion of Paragenesis Table.

Tourmaline commonly has automorphic contacts against the other early minerals (Figs. 3, 17) and was, therefore, the first mineral to begin its crystallization. In thin section, tourmaline crystals are seen to be fractured and the fractures are filled with some of the ore minerals (Fig. 17) and carbonate but in the same section part of the tourmaline occurs as automorphic grains embedded in the same metallic minerals and carbonate. Therefore, tourmaline continued to crystallize after the first episode of fracturing and also overlapped the crystallization of part of the ore minerals.

Oligoclase and the first generation of quartz and pyrite have xenomorphic, automorphic or mutual boundaries with one another and, like tourmaline, they are either intergrown with carbonate and the metallic minerals or have fractures filled by them (Figs. 4, 18). Since they have mutual boundaries with sphalerite and commonly contain automorphic inclusions of free gold and more rarely of chalcopyrite and galena they therefore continued to crystallize for a short time in the second stage of mineralization. Small, straight, narrow veinlets of pyrite in sphalerite are proof of a second generation of pyrite (Fig. 19). Since they do not occur in chalcopyrite and galena, it is believed that they crystallized shortly after sphalerite had completed its crystallization. A second generation of quartz occurs in the third stage of mineralization where it is intergrown with ankerite and rutile.

Sphalerite commonly occurs as automorphic inclusions in pyrite or fills fractures in it and is mutually intergrown with quartz, arsenopyrite and löllingite. It contains automorphic inclusions and interstitial masses of galena, chalcopyrite, free gold, tetra-

hedrite and pyrrhotite (Fig. 7). It is, therefore, believed to have been the next mineral to begin crystallization.

Free gold, chalcopyrite, galena and carbonate occur as automorphic inclusions and interstitial masses in pyrite, quartz and sphalerite; therefore they started their crystallization soon after sphalerite and overlapping pyrite.

Arsenopyrite and löllingite have mutual boundaries against sphalerite and in one case against chalcopyrite. They are mutually intergrown with irregular masses of pyrite along sphalerite-quartz boundaries but are not found as inclusions in cubes of the latter mineral. Therefore, they are believed to be contemporaneous with the later stages of the first generation of pyrite, which is represented by irregular masses of pyrite that occur along quartz-sphalerite boundaries.

Tetrahedrite occurs as inclusions or interstitial grains in sphalerite and its absence in pyrite and automorphic boundaries against chalcopyrite suggest that it crystallized later than the pyrite and earlier than the main part of the chalcopyrite.

Pyrrhotite, like tetrahedrite, occurs as inclusions in sphalerite or as automorphic grains in chalcopyrite and is therefore believed to be the same age as tetrahedrite.

Sylvanite occurs as automorphic or irregular inclusions in large masses of galena (Fig. 11) or in galena inclusions in sphalerite. Since it is not found in pyrite, its crystallization is later than that mineral but overlaps the crystallization of sphalerite.

Tetradymite and polybasite are intergrown with sylvanite (Fig. 13) and also occur as isolated automorphic or irregular-shaped inclusions in galena. They are not found in galena inclusions in sphalerite and, therefore, began crystallizing later than the latter mineral and completed their crystallization before galena.

Galenobismuthinite and aikinite are mutually intergrown with tetradymite and chalcopyrite (Fig. 15) and are therefore the same age as tetradymite.

Since altaite mostly occurs as irregular-shaped inclusions (Fig. 12) or as interstitial grains in galena it is believed to have crystallized during the later part of the galena crystallization.

Cubanite laths occur in chalcopyrite (Fig. 14) that is mutually intergrown with galena and in chalcopyrite inclusions in sphalerite. Therefore, its crystallization overlaps that of sphalerite. It is also intergrown with chalcopyrite and carbonate in small replacement veinlets along cleavage fractures in galena and therefore, like carbonate and chalcopyrite, continued its crystallization after galena.

Carbonate (chiefly calcite) is mutually intergrown with galena, chalcopyrite and free gold and therefore has the same age relations as these minerals. Carbonate (chiefly ankerite) is the dominant mineral in the third stage of mineralization and has xenomorphic contacts against ilmenite, specularite and rutile.

Sericite and chloritized biotite are intergrown with thin stringers of chalcopyrite and galena in quartz but their age is uncertain.

Muscovite occurs as automorphic grains in the carbonate of the third period of the mineralization.

THE ORE-BEARING SOLUTIONS.

Composition.—Changes in the composition of the depositing solutions appear to have occurred at the termination of the first and second stages of mineralization. The solutions of the first stage contained the following compounds and ions, either free or combined in various combinations, SiO_2, Al, Na, Ca, Fe, B, F and H_2S. The solutions of the second stage contained Pb, Au, Cu, Bi, Te, Ag, Fe, Zn, Ca, Mg, SiO_2, H_2O, H_2S, As, Sb and CO_2. The third stage was characterized by the precipitation of Ti, Fe, Ca, Mg, SiO_2, H_2O and CO_2.

Temperature.—The diagnostic minerals are tourmaline, oligoclase, pyrrhotite, muscovite, ilmenite, rutile and specularite. The first three occur during the first stage and early part of the second stage of mineralization and the last four during the last portion of the mineralization. These minerals are all indicative of high temperatures and pressures. Therefore, the ores are considered hypothermal. Tetrahedrite is generally considered mesothermal but the fact that it is contemporaneous with several definitely hy-

pothermal minerals suggests that it crystallized here under high temperature and pressure conditions.

Source.—The source of the gold-bearing solutions can, at best, be only conjectured. It is probable that the late fracturing of the porphyry dikes is due to the intrusion of a nearby igneous mass which could also have supplied the gold-bearing solutions. The nearest igneous mass, younger in age than the porphyry dikes is a granite massif which lies to the north of the Howey mine and, since gold-bearing veins have been found on the periphery of this granite; it may have been the source of the ore solutions that formed the Howey ores.

SUMMARY.

The Howey ore body is located in a series of dikes that are intrusive into the Keewatin lavas of the Red Lake area. A bostonitic andesite porphyry, the most acidic of the dike rocks, was intruded first. This was subsequently fractured and the fractures were filled with quartz. The second intrusion, a lighter tonalite porphyry, and the third intrusion, a darker tonalite poryhyry, show a progressive increase in biotite and decrease in quarfeloid content. Between the intrusion of the latter two dike types there may have been a period of fracturing and fracture-filling; all that is definitely known is that the andesite porphyry was fractured before the darker tonalite intrusion. Following the intrusion of the latter there was a period of fracturing and brecciation, and the fractures were filled with quartz and pyrite. The last dike intrusion, locally called "lamprophyre," is the most basic of all, and consists almost entirely of biotite. A period of intense fracturing and brecciation followed this intrusion, and the fractures were again filled by quartz and pyrite. These fracture-filling solutions caused silicification, sericitization and pyritization of the wall rocks. At this stage it is believed that an adjacent granite mass (McKenzie Island batholith) had begun to cool, therefore to shrink, thus relieving the pressure in the surrounding rocks and producing fractures that were filled by the residual liquid from the granite. The occurrence in the veins of such common magmatic minerals as oligoclase, rutile, ilmenite and specularite, the common pneumatolytic minerals, tourmaline and muscovite,

and the usual hypothermal mineral pyrrhotite suggests that the nearby granite was the probable source of the ore-solutions.

Evidence that the veins were formed by fracture-filling and not by replacement is offered by the following facts: (1) The veins are lenticular in shape. (2) They have straight, knife-edge contacts against the wall rocks. (3) The tourmaline-quartz-pyrite veins are slightly banded. Tourmaline lines the walls, pyrite next and the center is filled with quartz, oligoclase and a small amount of carbonate. (4) In thin sections vein quartz has a conspicuous comb-structure.

The mineralization was probably a continuous process but is divisible into three episodes or stages, each separated by an episode of fracturing. The earliest minerals to crystallize—tourmaline, oligoclase, pyrite and quartz—were fractured during their crystallization, and this fracturing terminated the first stage of mineralization. These minerals continued to crystallize during the early part of the second stage of mineralization, which is characterized also by the crystallization of pyrrhotite, löllingite, arsenopyrite, sphalerite and tetrahedrite. The crystallization of free gold, galena, chalcopyrite, cubanite, sylvanite, tetradymite, altaite, polybasite, galenobismuthinite, aikinite and carbonate occurred at various times during this second stage of mineralization which also ended with fracturing. The third stage of the mineralization resulted in the crystallization of ilmenite, specularite and rutile in a gangue of predominant ankerite and smaller amounts of quartz, muscovite and calcite.

The composition of the carbonate and its importance as a gangue mineral changed during the process of mineralization. In the early part of the second stage of mineralization it was calcite but it was unimportant in amount. As mineralization progressed the amount of calcium decreased while magnesium and iron increased and the carbonate as a whole gradually supplanted quartz as the chief gangue mineral, with the result that in the third stage of mineralization the gangue consists almost entirely of ankerite.

DEPARTMENT OF GEOLOGY,
UNIVERSITY OF CHICAGO,
January 23, 1937.

THE TIN ORES OF BANCA, BILLITON AND SINGKEP, MALAY ARCHIPELAGO. PART II.

Continued from last number.

NICOLAAS WING-EASTON.

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ORE DEPOSITS.

Disintegration Deposits and Their Relation to Veinlet Zones.

Origin of the Kaksa Beds.—Koolit-Kollongs.—No factor of the economic geology of the tin islands has raised so much discussion as the origin of the kaksa beds and the presence of the overburden, and the question "Why ore is where it is" has not yet been settled with respect to these deposits.[37] As regards Billiton, those best qualified to judge have reached unanimity of opinion about the principal questions and, at present, one cannot reasonably insist upon a divergent origin for Banca.

[37] Not in these islands only. H. Herman thinks that detrital ore from Mount Bischoff is negligible, and that most of the so-called alluvial deposits are true lode material of peculiar character (Jones, Tinfields of the World, p. 368).

One of the just problems to be considered is the warm, dry climate that must have prevailed in the islands for a long period. The water courses, which had been formed in the preceding damper period, remained, but most of the water disappeared. Dry weathering gave rise to side-erosion by crumbling off; the gravel and boulders which formerly had been deposited fell asunder.[38] Deflation transported most of the finer dust to the sea. The combined result was that the valleys widened and the floors were covered only by a thin layer of sand mixed with a few fragaments of more resistant material.

Properly speaking, the effect of atmospheric weathering on the solid rock was the same inside and outside the valleys and, as this rock shows in places alteration to a considerable depth, the groundwater level must have been lowered to this extent at least, and this also testifies to the very low stand of the sea level in the period of the elevation of the country. Such was the situation some time before the end of the intrusion and the beginning of the period of mineralization.

The trunks of trees laid bare in Singkep as well as the logs of wood and the resin found in the kaksa indicate that some valleys had been wooded here and there shortly before the kaksa formation. This feature points to the initiating of a slight change of climate; rain was less rare; the groundwater rose to a higher level, and not long afterwards temporary rivulets made use of the existing valleys. Meanwhile mineralization set in; where the vein zones spread outside the valleys, koolits could be formed; inside the valleys the combined action of weathering and deflation made the veins stand out from the floor until they were dissolved by the occasional running water. Furthermore it may be taken for granted that in the spaces between many veins in granitic rocks greisen had been generated, which fine and brittle material soon disintegrated. Such mineralized portions of the valleys, therefore, readily deepened and the ore could be concentrated in a kaksa bed in which most of what had been left of the former sandy remains was assimilated.

[38] The quartzites also weather similarly; *e.g.* near Papan, Billiton, fragments of a tough quartzite have become friable by exposure.

As the chemical composition of the gases that invaded the granite cannot have been dissimilar from those that penetrated the sediments, some kind of greisenization of the latter may also be presumed. In fact, the common change of the soft sandstones into hard quartzites, and the generation of mica in many clay shales as well as their hardening by silica, are as characteristic of this mode of alteration as the impregnation of some shales and sandstones with tinstone and tourmaline.

Assuming that sufficient time was available for the kaksa to form, there might be some doubt as to whether the tenor of ore in the veins was high enough to produce the rich kaksa beds that have been worked. The experience gained at Pemali (Example 9) proves that there is no reason for such doubt. Supposing that the ore in that deposit is equally distributed (0.25 per cent.), then, if a slice of this ground, 7½ m. thick, is reduced to a kaksa bed of 0.75 m. height, the latter contains 2½ per cent. of tinstone. As Pemali is neither a specially selected case nor an exceptionally rich deposit, and as the mineralization of the islands has been most intense in proximity to the surface (page 164), the kaksa will be considerably richer in many other cases, especially where broader veins have contributed to its formation, as has often occurred.

The valleys as we know them to-day are the outcome of various factors. Many former rivers may have been shallow and narrow except perhaps in the lower courses of the main streams; they became laterally extended, dish-like, during the long period of drought; and their present shape has been completed in Quaternary and sub-recent time. Considering the low capacity of the present rivers, their carrying power in the latter periods cannot have been great. An appreciable part of the quartz and tourmaline, minerals of smaller density, remained in the kaksa, so there was certainly little chance that the tinstone could be removed, except in the headwaters in areas where the hills were abundantly mineralized, or in an exceptional case such as that discussed by Dr. Wilhelm, where piracy of a river had taken place.[39]

[39] *Op. cit.*, pp. 114–118.

In the valley banks atmospheric weathering would act from above as well as laterally and, if veinlet zones were present, koolit formation would have been more intense here than in places more remote from the valley. However, the sloping ground of the banks afforded an opportunity to the percolating rain water to carry off the lighter substances and, consequently, the result was that, just as in the valley itself, not a koolit but a kaksa bed was formed, here lying at a higher level, but in a later period, likewise buried under clay and sand. Such a "high-side working," in places resembling a terrace formation,[40] was called a *koolit-kollong*, this term signifying that there was kaksa as in a kollong, but that the ground was worked as a koolit, or, in other words, it was geologically a kollong and technically a koolit. Many koolit-kollongs pass gradually into typical kollongs on the one side and into typical koolits on the other; many others, however, occupy a more independent position; the reason for this diversity can only be guessed at for want of accurate data.

Dr. Rueb states [41] that

> on the Manggar flat the kaksa in the kollongs and koolit-kollongs forms one continuous layer covering the bedrock everywhere, being thin in one place and thick in another, here poor and there rich, disregarding the depth of the bedrock and lying sometimes above the present sea level, but in places down to 20 m. below it.

On this flat the Manggar and Landji rivers may have anastomosed and changed their courses in former times.

From what has been stated it is clear that koolit and kaksa originated in the same way. The only points of difference are that the kaksa was reduced by running water to a fraction of its original magnitude, without being changed in character, and that its formation took a comparatively short time, whereas only a small quantity of the koolit material was carried away, the concentration of ore in it was more evident, and its formation continued until recently.

I was told that in Billiton some valleys were found where the usual overburden was absent, and the bottom covered with a

[40] Wilhelm, C. H. J.: *Op. cit.*, p. 50, with ill.

[41] *Op. cit.* (1920), p. 9.

koolit formation (Sagoe valley, Mengeris valley). In order to make working possible, such valleys had to be embanked; and the deposits might be termed *kollong-koolits, i.e.,* geologically koolit and technically kollong. They clearly illustrate the truth of the statement above.

Formation of Overburden; Subsidence and Periods of Regression.—Although the intrusion caused the land to rise, it later began to sink. As stated previously a slight change of climate set in at about the same time, and gradually became more pronounced after the kaksa had been formed. The effect was that the products of erosion and deflation, which had been accumulated in wind-sheltered places, began to move and partly slid down into the valleys. The heavier quartz settled almost immediately, whereas most of the clay was carried off to the sea.

In course of time the sea invaded the mouths of the rivers; transport came practically to a standstill in the valleys; and the clay, too, was compelled to settle. Local circumstances and a divergent composition of the material may have modified the sequence of the deposits even in the same valley, but normally the sand lies lowermost and the clay uppermost.

This seems to be the most plausible explanation of the formation of the overburden. Another part of the products of erosion was not buried in the valleys but came to rest in other suitable places. After having been exposed to rain wash for a long time, only a sandy soil of very unequal thickness was left, which at present covers a considerable part of the bedrock in the lower parts of the islands.

The period of the growth of the overburden might also be called the period of sidelong creep, and this kind of transport may occasionally have affected the weathered ore-bearing surface layers of the valley banks. Some recorded instances of abnormal locations of ore in the valleys may be due to this change of profile.

The subsidence of the land is made evident by the finds of marine shells immediately upon the kaksa, or at some distance above it; by the coral reefs that fringe most of the islands of the

Banca-Billiton archipelago; and by the broad and shallow inlets of many rivers. From some observations in Billiton it may be inferred that the sea level was once some meters higher than nowadays and, the deepest kollongs being about 25 m., the minimum submergence of this island may be estimated at about 30 m.

The sinking was not uninterrupted; there were periods of rest and even of regression, during which the rivers formed temporary beds in the overburden. As a rule the new bed was not well-defined, owing to the softness and inconsistency of the clayey material; but if the latter happened to be tin-bearing to a certain extent, its former presence is indicated by a layer of mentjang ore. The source of this kind of ore cannot be traced; it may lie quite close to the deposit or farther away but, as is easily understood, it can never be the same as that of the kaksa underneath.

Instances have been recorded of two and even three mentjang deposits one above the other, and at least as many periods of regression will have to be assumed. Commonly, however, the overburden was barren or very poor in ore, and then the record of such a period is lost. Under favorable conditions the outlines of such a temporary river bed may have been beautifully preserved, as shown in a photograph by Dr. Wilhelm [42] reproduced as Fig. 13.

Sea-Tin Deposits.—A continuation of ore-bearing sediments at the sea bottom has been mentioned (Example 1). At first it may seem strange that such a case is rare, since payable ore deposits commonly reach as far as the utmost border of the land; but consideration of the bearing of the epirogenetic movements on the position of the islands shows it could hardly be otherwise.

The upward warping affected the whole belt, and elevated a considerable part of the epicontinental platform. In addition to this general rise, the islands under review were individually uplifted in their own fashion by the " fangs " with the consequent dividing of most of the valleys into two parts. The landward part was elevated to a higher level, unless tilting took place in an oblique direction, in which case the situation remained almost unchanged

[42] *Op. cit.*, p. 48.

on one side of the island. It may reasonably be assumed that the mineralization was not confined to the present outlines of the islands, but generally the kaksa, which might have been formed in the seaward parts of the valleys, was afterwards disturbed by the action of the returning sea and then concealed by various marine deposits. Sea-tin deposits occur only where a mineralized stretch of ground happened to be part of a gently sloping shore, which is still immersed at present.

The best example is that of the southeast coast of Singkep where for more than 20 years such deposits were worked with great profit. After it had been ascertained that the rich portions of the lower Dabo valley continued below the sea level without any change of character, a series of 2340 bore holes were drilled in ranges running parallel to the coast line. Several submerged prolongations of existing valley deposits were discovered and, in the interspaces of these, beds of submerged koolits. The working result was that two bucket dredges gave a net return of about 6000 tons of tin.

On the shore line the bedrock in the Dabo valley lies at a depth of 12 m. and in the sea at the end of the payable kaksa it is at a depth of 17 m. This same coast is fringed by a boulder bed [43] consisting of quartzite, tourmaline, hornfels, quartz, limonite, and other hard débris of the sediments, evidently piled up by the surf and reaching its maximum height of 4½ m. above sea level at Loempoer river, where it has a level surface covered by an ore bed with an overburden of sand and clay. The latter is of very unequal thickness, between 1½ and 8 m., and clearly shows that its origin is due to wave action—cross-bedding, subangular and rounded forms of the minerals, concentration of the ore in the undermost part, ill-defined boundaries of the layers. From this it follows that the former sea level was $4\frac{1}{2} + 8 = 12\frac{1}{2}$ m. higher than at present, and that the minimum submergence of Singkep may be estimated at $17 + 12\frac{1}{2}$ or about 30 m.

Investigations outside the shore lines in East- and West-Billiton did not meet with success.

[43] Wilhelm, C. H. J.: *Op. cit.*, pp. 53–58 and 118–119.

For a long time several places have been known along the eastern coast of Banca where tin ore could be washed from the beach sand, occasionally with a little gold, but recently a deposit was found and worked in the submerged prolongation of the Mesoe river, Pangkalpinang. Judging from a longitudinal section published by Mr. Geursen,[44] the kaksa in the land part of the valley rests as usual upon the sedimentary bedrock, at a depth of 12 m., but, suddenly, this kaksa bed comes to an end, and in the adjacent sea bottom the following layers occur, *viz.* (topmost) (1) sandy marine clay with shells, 2 m.; (2) cross-bedded sand and yellowish clay, 3 to 4 m.; (3) a poor ore bed covering only part of the valley; (4) sand and clay with current bedding and with some intercalated lenses of black bituminous clay, 6 m.; (5) second ore bed, richer than the preceding; (6) white sand and clay, 3 m.; (7) third and rich ore bed with boulders of quartz and kaolin; (8) fine, firm sand, probably fluviatile, 11 m.; (9) fourth ore bed, not yet worked.

The latter bed is at 32 m. and the bedrock is presumed to lie underneath but has not yet been reached by the drill on account of the presence of boulders of hard quartzite.

In my opinion convincing evidence is furnished here of the fact that the original Mesoe valley has been divided by the "fang" elevation of the island into two parts; the one on the south being elevated 20 m. (32–12 m.). The mineralization affected both parts, and the one on the northeast has been covered with the usual overburden partly supplied by the landward part of the river; in the three periods of regression mentjang beds could be formed. Here again the sand lies immediately on the kaksa (the fourth ore bed). The sheltered position of this lower-lying part of the valley permitted the quiet deposition of the overburden, which elsewhere has been removed by the ocean currents.

A longitudinal section of the Tempilang valley (Fig. 3) in the southeastern corner of the Muntok district, was also published by Mr. Geursen.[44] In this case, as in Singkep, the kaksa in the

[44] Geursen, G. J.: De Myningenieur, 1933, p. 178.

valley continues for about 1500 m. on the sea bottom at a depth of 18 m. on a "weathered" granitic bedrock. Some ore (mentjang) was also found above the present high-water level.

There is reason to suppose that Banca and Singkep have been elevated obliquely, whereas Billiton has been raised more uniformly and perpendicularly.

From the available data it could be inferred that the minimum submergence of the three islands was ± 30 m.; this is only the visible submergence computed from some established facts. At present there is a new period of regression; it may be that this period is only temporary like the preceding and that, when it has come to an end, the islands will be flooded once more and then to a greater depth than before.

Consequences of the Subsidence.—The overburden had concealed the kaksa beds before and during the period of subsidence, so these beds were protected against disturbance. But the sea was effective in another way.

(1) The sea attacked the koolits on the lower levels, removed a part of the sterile matter, and wiped out the difference between koolit ore and kaksa. This feature is conspicuous in the flat country to the west and northwest of Manggar; the koolit ore being commonly covered by a thin sandy layer, it simulates a kaksa, but there is no valley.

(2) The ocean tides could replace or support the action of the rainfall on surfaces that were too flat to permit the gravitational sliding down of the erosion products into the valleys. A curious instance of this on the southwest coast of the Toboali district, Banca, has been published by Mr. Geursen.[44] (Fig. 4.) A former depression, 10 m. deep, lying between two existing streams, had been entirely filled in with the usual overburden, but kaksa is lacking. The granitic bedrock is covered partly with clay, partly with ore,[45] the latter overlapping the former. The top layer is also ore and simulates a koolit. A third small ore bed is intercalated in the overburden. Here, too, the three periods of regression have been marked by three mentjang beds.

[45] Ore is here meant in the sense of a mixture of quartz and cassiterite.

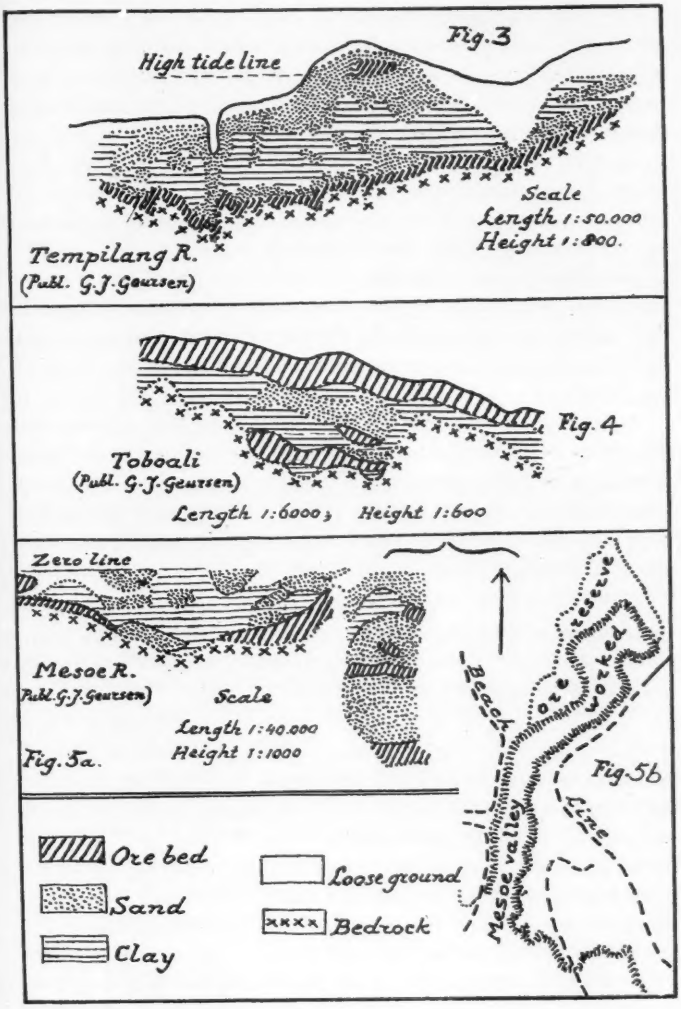


Fig. 3
High tide line
Scale
Length 1:50.000
Height 1:800.
Tempilang R.
(Publ. G.J. Geursen)
Fig. 4
Toboali
(Publ. G.J. Geursen)
Length 1:6000; Height 1:600
Zero line
Mesoe R.
Publ. G.J. Geursen)
Scale
Length 1:40.000
Height 1:1000
Fig. 5a.
Beach
ore reserve worked
Fig. 5b
Line
Mesoe valley
Ore bed
Sand
Clay
Loose ground
Bedrock

FIGS. 3, 4, 5.

(3) The sea having reached the embouchure of a valley, the surf could bring in lumps of the local rocks and grind them to slabs and boulders. Under suitable conditions the latter may have come from rocks situated at some distance. In the overburden neither boulders nor slabs have been found.

(4) As was exemplified at the mouth of the small Pasir Atas valley, Soengailiat, the surf removed all the clay, and churned up the rest, leaving only a layer of tin-bearing tet-si-koi on the bottom covered with a thick deposit of sand rich in ore.[46]

The Tin Ore: a Near-Surface Deposit.—Though subsequent experience revealed the untenability of Dr. Verbeek's conception that the tin ore in the islands was of supergene origin, he was right in one respect, *viz.* mineralization was most intense close to the surface.

It was usually maintained in writings on this subject that deposition of cassiterite is only possible at great depths and that, when it is actually found near the surface, denudation of great magnitude must have preceded. After reflecting on what might have taken place during an intrusion, the present author was long ago convinced of the unlikeliness of this theory where Billiton is concerned, and in 1925 he wrote [47]

> One is compelled to come to the conclusion that the island, from the period of the appearance of the pneumatolytic emanations, has substantially exhibited the same aspect as nowadays, which implies that erosion has played only a very modest part.

This verdict was based on the following considerations. If an intrusion remains in depth, the upper parts of the overlying rocks remain undamaged, and the magmatic residuals cannot escape. If, however, as in Banca and Billiton, the intrusion rises into higher regions, the shattering and fissuring of all the overlying rocks will be a common feature; outlets are available to the residuals, and their velocity of ascent is much increased. The result is a serious decline of outer pressure, whereas the fall of temperature is unimportant. A moment must arrive at which the

[46] Verbeek, R. D. M.: *Op. cit.*, p. 146, no. 12.

[47] Verh. Geol. Mynbk. Gen., Geol. Serie, vol. 8, p. 151, 1925. Also stated in my report to the Billiton Co., 1920.

volatile with the major vapor pressure is suddenly expelled, soon followed by other volatiles with somewhat smaller vapor pressures. They invade the numerous cracks, but before long the conditions are such as to make interaction inevitable. Therefore, where a high enough temperature coincides with a low enough outer pressure, as occurred in the tin islands, there can be no objection to assuming the possibility of a deposition of deep seated minerals even in the uppermost regions.[48]

The evidences are the following:

(1) A slight amount of erosion sufficed to bring forth the loose ore beds. (*a*) Erosion of 7½ m. of a moderately rich primary deposit was calculated (p. 156) to produce a payable kaksa; (*b*) The lode of stanniferous iron ore at Seloemar stands out 6 m. above the surface; (*c*) The portion of the veins which produced the kaksa can never have been higher than the depth of the valleys, which, in the middle courses, averages 6 to 8 m. (van Diest). These three mutually independent figures harmonize pretty well and are the standard by which the difference of level between the present and the former surface may be measured. It stands to reason that the rate of growth of an eluvial koolit was much slower than a kaksa; in fact, its depth never surpassed 3 m.

Both koolit and kaksa are near-surface deposits. Abnormally rich areas in a koolit or valley are always of limited extent and connected with rich veins or stockworks, but not with a greater height of erosion.

(2) The outcrops of all the broader veins known have been rich; the upper part of the Tikoes quartz body was much richer than the lower. Nowhere did the deeper parts of the primary-ore occurrences prove richer than the upper parts.

(3) The heavy lumps of tinstone alluded to above, occurred exclusively in koolits on sediment in the richest part of Billiton. The irregular pieces are by far the bigger and had nothing to do with veins; they cannot have been shifted far on account of their weight, and they offer striking examples of near-surface deposits. I advance the following theory about their origin. Suppose a

[48] About the same reasoning is to be found in Niggli-Boydell: Ore Deposits of Magmatic Origin, p. 8.

fissure of medium width had its aperture at the surface, then the friction along the walls may have lessened the velocity of the gases to such an extent that those, which had not yet deposited their metallic load, arrived at the orifice with so small an ascending power that a few meters of overburden sufficed to prevent their escaping in the air. This overburden was vaulted a little and the interaction of the gases took place in the empty space. Since the valleys were not filled during the period of mineralization, such ore lumps could not originate there; these are, indeed, restricted to koolits.

Very few records of those lumps came to our notice, but the two I could lay my hands on do not contradict my theory, *viz.* (1) Mr. de Groot reports [49] that in 1869, when cutting a ditch near Manggar, an ore lump of about 40 kg. was found, the crust of which, to a thickness of 6 or 7 mm., was an aggregate of quartz-sand with some cassiterite, whereas the balance consisted of pure ore with little quartz. (2) A heavy cake of almost pure tinstone in the shape of a semi-lens was found lying with the convex side up in a cup of the bedrock of a koolit-kollong near the Lais valley, southeast Billiton.[50]

The ore lumps which display their origin from veins, have always been found in the upper parts.

Danger of the Use of Native and Chinese Terms.—The practice among European functionaries to use the native or Chinese terms, but not always using them for the same thing, has given rise to much misunderstanding in the discussion. A short account of it may be of interest to those of my readers who intend to study the Dutch literature on the subject.

A *koolit* is the outer part of something; it must, therefore, belong to it. A koolit proper in tin mining, the "eluvium," must belong to the bedrock, and indeed many were koolits *stricto sensu.* The term, however, though originally bearing a geological meaning, was soon used only in a technical sense after the discovery of the valley deposits.

Where rich veins occurred on sloping ground, the products of

[49] *Op. cit.*, p. 193.

[50] Oral communication from the District Officer of Lenggang.

their disintegration were given an opportunity to gravitate down (to creep). The hills Tikoes, Klapakampit, and Seloemar in Billiton; Toemang and Kapitan in Singkep; Sambonggiri in Banca were famous for the rich ore beds on their flanks and their nearest surroundings. These beds, mostly covered by a thin layer of rock débris, were called koolits, because they could be worked as koolits, but, in fact, the ore was not produced from the *immediately* underlying bedrock which, in part, might even have been sterile.

As long as the ore was found along the slopes, the evil done by the wrong use of the term koolit, was of little importance, but portions of the ore happened to come to rest in adjacent valleys, afterwards simulating kaksa, and speculations have been made concerning its origin in connection with the color, size, and wear-and-tear of the tinstone.

Koolit ore lying on a bedrock which is not its own, is of course a " false koolit "; this may have occurred more than is generally known, for instance in proximity to the junction of the two principal country-rocks, where creep may have played a part in the period of a more abundant rainfall, so that ore containing granite débris could shove over the sediments.

The original meaning of *kaksa,* an ore bed in a valley lying immediately on the bedrock, is also a geological one and it is, therefore, necessary to keep this definition in view. There are numerous instances in which this term is used wrongly for the intercalated ore beds, though these have been given the appropriate name *mentjang* by the Chinese. In the present paper the strict observance of the difference has enabled the writer to elucidate in a simple way the mystery of some anomalous deposits.

Other authors speak of kaksa when they refer to any loose ore bed of greater or smaller extension, and they also coined the terms " koolit-kaksa " and " kollong kaksa," the former being a *contradictio in terminis,* the latter partly superfluous, partly inappropriate, because the working method has nothing to do with the formation of the ore bed.

BED ROCK DEPOSITS.

General Observations.—The natives of Billiton were acquainted with the occurrence of *loose* tin ore on or just below the surface, and for many years they succeeded in keeping it secret from every foreigner. But the existence of tin *veins* was known to the then assistant-resident Bierschel as early as 1824, and the first Dutch pioneers in Billiton (1852–1860) Messrs. J. F. Loudon and V. Baron van Tuyll knew about the veins of Brang and Tadjau. They took rich samples of the outcrops to Europe and had the veins explored, the one of Tadjau even for a period of six years, but with disappointing results. Seemingly the ore persisted neither in strike nor in dip; and as experience had already shown that the working of the secondary ores was more easy and profitable, that of the primary ores was abandoned.

Attention has been called to the fact that in Banca as well as in Billiton, the working places for the Chinese were outlined by the officials who, however, paid little attention to the actual operations. In Billiton, however, they were aware that in numerous koolits and kollongs broader veins had been found and broken down—in places to a fairly considerable depth—the output of which had been accounted for as "alluvial ore." These veins constituted what they called the "good luck," and in the Billiton Memorial Volume I, p. 99, it is stated: "The outcrop of a vein was very rich, very easy to work too, and the ore was about as pure as alluvial ore." The richness could be inferred from the large output per head; the fact that the unskilled Chinese could perform this mining, testifies to its easiness; but the ore was pure only because in those near-surface parts of the veins, pyrite was scarce and had mostly been changed into soft limonite, from which tinstone can be readily separated by crushing and washing. That big lumps of almost pure cassiterite were occasionally found in the veins, has been mentioned.

The Chinese, however, were unable to separate the tinstone adequately from the fresh pyrite and when this increased with depth, the work ceased. The work also ceased by order of the Company when rare galena or chalcopyrite were found, because

these materials deteriorated the tin metal. A third reason for stopping the work was the tapering off of the deposit which lowered profits.

As a rule, therefore, the working of the veins did not last long, and since the officials cared little about the reason, they assumed that the lower parts were unprofitable. No records concerning the filling were kept, nor any surveys made; when the operations had been concluded, the excavation was commonly used as a tailing dump, so that the exact trend of many veins was not mapped, an omission that caused difficulties, failures, and great expense later on. Thus, the number of veins formerly worked or "skimmed off," is not accurately known, but about 30 have been systematically explored and several of them exploited in the present century.

Most of these veins are very irregular, not only in width but also in ore content. Further, rapid fluctuations in the price of tin pruned expenditures, and sudden drops in prices caused immediate cessation of operations. Difficulties were experienced in the treatment of the pyritic ores; years passed before an effective method was found, and experience was costly.

The working area allotted to a Chinese party was always restricted, and in places the veins were narrow and unobtrusive. Consequently, three or four old vein workings, known by different names, might be parts of a single vein of some kilometers in length, perhaps separated from each other by minor cross faults. The exact length of these long fault-fissure veins is not known; generally the portions worked or tested do not exceed a few hundred meters and they have been tested only to shallow depths. That they may have been rich in tin, is inferred from the records of the Mangkoebang vein. This vein, from 1 to 2 m. wide, was discovered in 1868 projecting from the bedrock of a koolit, and a length of about 200 m. was mined to a shallow depth. Some distance away, it was rediscovered, and from 1897 to 1902 mined to a depth of 40 m. With an average extraction of 2.23 per cent., the vein produced 560 tons of tin in these 6 years.

Networks.—The deposits formerly worked in Billiton under the name of " veins " all occur in sediments, but are not all alike; they consist of networks and veins.

The former are a network of stringers that follow bedding and joint planes, mostly in sandstone, and so closely spaced that the whole mass was mined for ore. They occur in Banca, Billiton and Singkep, and have already been described by Dr. Verbeek. In Billiton some were rich, but payable only to shallow depths. In Banca, they persist, in places, to a much greater depth and with a higher ore content, and perhaps constitute an important future ore reserve. There is a possibility that such ore may also be present in Billiton, but the probability is not great if my supposition (pp. 6, 23) about the thickness of the sediments is correct. These networks are commonly connected with typical veinlet zones, which yielded almost pure tinstone, and with other broader veins that contained pyrite, and have produced " kreekil."

In Billiton some of these network deposits were worked for many successive years. In the upper levels an extraction of from 0.7 to 0.9 per cent., was reached which, however, quickly declined to 0.3 or 0.4 per cent. At present they are abandoned and probably will never again be worked.

Fracture Veins.—The deposit of Klapakampit in Northeastern Billiton illustrates the complex pattern of the veins that occur in hills. In my opinion they arose from the warping of the sediments, either through the upward pressure of the magmatic residuals themselves or through that of a hidden core. The warping gave rise to cracks, chiefly along the bedding planes, but also more or less normal to these. Slight movements of the blocks are not uncommon; some walls are distinctly slickensided.

In places the sediments have been curved or even folded, and then the fissures run right across them. Nearly all of the fissures have been mineralized. The outcrops everywhere contained much ore, and have produced rich koolits with numerous large pieces of pure tinstone, which also occurred in the upper levels of the worked veins.

The latter vary in width from mere cracks to 1.5 m. The tin-

stone is unequally distributed. Some of the veins near the surface resemble the networks, but at greater depth the ore body commonly consists of one or two rich streaks within leaner material. Since the wall rocks are also more or less impregnated with ore, the vein assumes the character of a lode.

At the outset these veins were tested by open cuts or trenches, and the irregular distribution of the ore and the absence of ore shoots made the removal of the whole mass inevitable. After it had been ascertained that payable ore persisted farther downward, and the deep excavations became dangerous, deep mining followed. In 1931 the underground workings were, at a depth of 82 m., connected with those of the Raya vein which will be mentioned below.

Everywhere the fissure filling is rich in ferruginous minerals which, near the outcrops, have been altered to soft "limonite" or to hard oxides of iron, so that the deposits are iron stained. In 1920, however, I observed, not far below the surface and at some distance above the groundwater level, an appreciable quantity of pyrite which increased farther down. Although the veins proper may be very rich, the average tenor of the lode is not high, owing to the amount of lean material that has to be extracted.

The following figures of extraction of milled ore, taken from the 13 Annual Reports between 1917–18 and 1929–30, indicate the constancy of the ore grade, *viz.*, 1.03—0.75—1.14—1.20—0.77—0.67—0.82—0.75—0.78—0.60—0.75—0.82—1.38, giving an average of 0.88 per cent. Since 1930, the ores of the hill mines and those of the Raya mine have been jointly treated in the new mill. The average of 0.88 per cent. in terms of tin corresponds to 1.25 per cent. of cassiterite and assuming a 60 per cent. extraction, the original ore grade may be estimated at 2 per cent. tinstone. Figures of the tenor of the crushed ore, however, have not been published. In the 13 years from 1917 to 1930, the total output of the hill and its underground continuation, was about 4000 tons of tin.

Fault-Fissure Veins.—These veins dip steeply parallel to the

strike of the sediments. They occur mostly in sandstone but also near or on the shale contact. They are all found in the eastern half of Billiton; three of them have been developed and partly worked from shafts. As the size of the tinstone becomes smaller on the lower levels, making treatment more expensive, mining is profitable only with high tin prices. Consequently, at present these veins are not being mined, except at the Raya lode to the northeast of Klapakampit. In this mine the deepest level was 192 m. in 1931, and the ore extraction was respectively 1.84—2.66—1.27—2.19—3.08 per cent. for the years from 1926 to 1930.

There is no description of this vein available, but it probably is similar to the Garoemedang vein described by Dr. Groothoff.[51] From his article the following data have been extracted:

The junction of vein and country rock is generally imperfectly defined, for the sediment close to the vein is so intensively altered and impregnated with ore and other minerals that it constitutes an integral part of the filling. The lode structure varies greatly; the central part is generally massive and the margins banded. The filling is very complicated and, in addition to the common constituents, pyrite, quartz, cassiterite, and tourmaline, it contains at least twelve other primary minerals which, however, are found in abundance only locally. The vein has been little disturbed; some cross-faults of minor importance only were observed.

The bulk of the filling consists of pyrite, and siderite may be present. Some parts of the vein consist of massive pyrrhotite mixed with pyrite, quartz, mica, chalcopyrite, and cassiterite. Arsenopyrite and chalcopyrite are not uncommon. Magnetite in finegrained aggregates or fairly well crystallized, commonly occurs in the sediment close to the vein proper, associated and in places intergrown with tourmaline, rarely with garnet and tinstone.

Fibrous amphibole, almandine, fluorspar, and lithia mica are fairly abundant in some places and entirely lacking in others.

[51] *Op. cit.* (1916), p. 74.

Beryl, lazulite, wolframite, specularite and orthoclase are rare. Masses of rather pure cassiterite occur here and there, but in the main intergrowths of tinstone are found with any other of the common primary minerals; generally the crystals of tinstone are simple and stained a deep brown color by iron.

The mutual intergrowth of different minerals justifies the conclusion that they were formed almost simultaneously, except that the oxides were among the earliest. Some of the accessory minerals apparently originated through interaction of the magmatic substances and the constituents of the sediments. The process of generation of fibrous amphibole, of greenish-yellow mica, and of tourmaline, from the clay of the shales or the argillaceous cement of the sandstones, can be studied under the microscope.

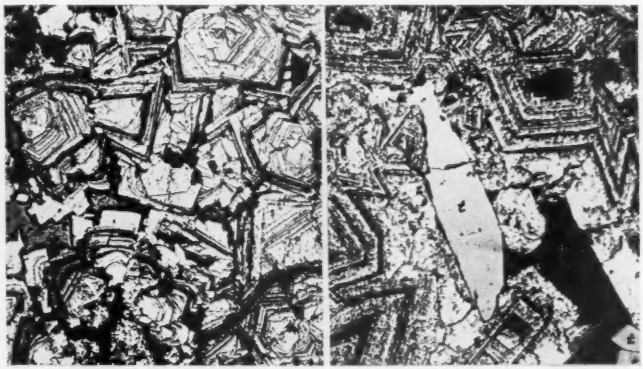


FIG. 6 (left). Pyrite (Huelva, Spain), etched with HCl.
FIG. 7 (right). Magnetite (Seloemar, Billiton) with tinstone (t) but without a trace of pyrite, etched with HCl.

Fault Veins with Gossan.—There is a peculiar difference between the fault veins situated in the Manggar flat, *e.g.*, Mangkoebang and Garoemedang, and such as are found on the hills north and south of it. The latter possess a cap of oxides of iron—magnetite and hematite—in some cases rising to a few meters above the surface. With the former such a cap is wanting;

the outcrops are stained by brown "limonite," but commonly pyrite appears at shallow depths.

Probably the reason for this difference is the following: Soon after the pyrite had been altered into "limonite" in the outcrops on the flat, these were flooded by the sea on the occasion of the subsidence of the island; the surf may have crumbled the softer parts. They remained for a long time under water and, when the sea had withdrawn, a new gossan could not be formed in the present humid climate. The outcrops on the hills, on the other hand, escaped flooding; for a long time their gossans were exposed to the sun, hardened, and, erosion having lowered the hills, they project up as walls, unless they have been disintegrated into large blocks.

The best known of these ironstone walls, is the one on the southwest slope of Seloemar hill, which has been exploited, first by tunnelling, later on by underground mining to a depth of 68 m. The ore stuff above the 42 m.-level was of good grade, and samples taken from the outcrop in 1910 yielded from 1.4 to 4.5 per cent. tin; but the fineness of the tinstone in the deeper parts led to disappointing results. Since 1921 the mine has been closed.

By 1914 the vein had been traced and developed for a length of over 1200 m., disclosing a width of from 2.5 to 5 m. It appeared that the hard gossan did not extend downward, because in the highest tunnel the lode material was fairly soft, and on the 42 m.-level of the shaft nearly everything was "limonite" with little pyrite. Consequently, the lode consisted in the main of a tinstone-bearing pyrite. That the magnetite of the gossan is of secondary origin was proved by Mr. Schouten,[52] who demonstrated that polished surfaces of this material, in which there was not a trace of pyrite, and of a sample of pyrite from Huelva, display similar structures after having been etched by HCl, as is shown in Figs. 6 and 7.

It has been mentioned that magnetite has been formed in the outer shells of the kreekil-pebbles, and the same is true of the

[52] De Myningenieur, 1927, p. 144.

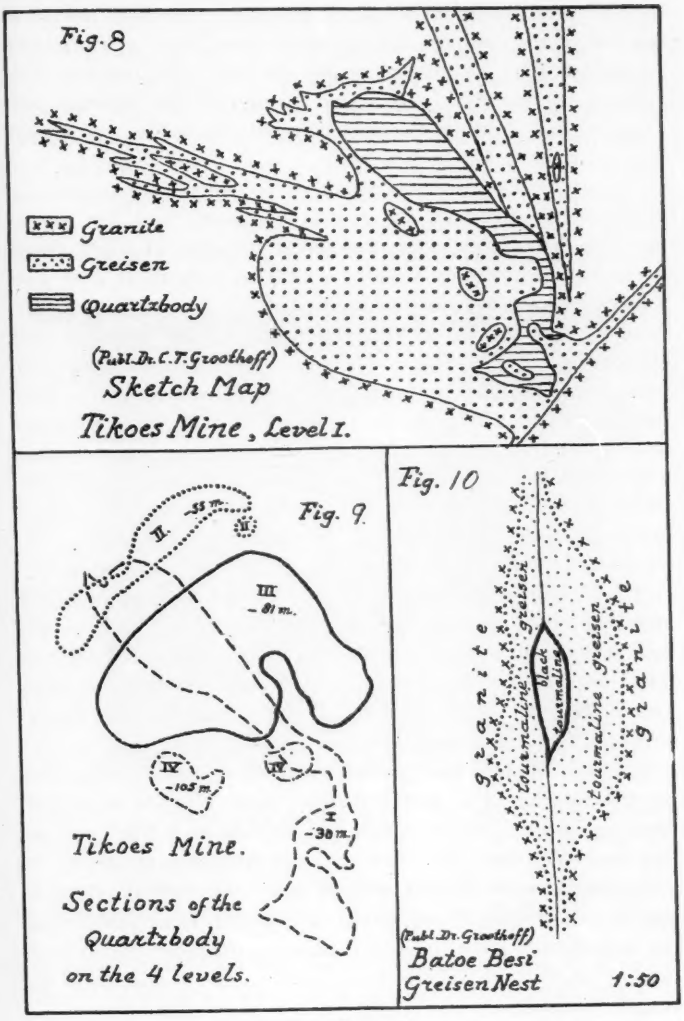


Fig. 8
Granite
Greisen
Quartzbody
(Publ. Dr. C. T. Groothoff)
Sketch Map
Tikoes Mine, Level I.
Fig. 9
II
-55 m.
III
-81 m.
IV
-105 m.
V
I
-30 m.
Tikoes Mine.
Sections of the
Quartzbody
on the 4 levels.
Fig. 10
granite
tourmaline greisen
black tourmaline
tourmaline greisen
granite
(Publ. Dr. Groothoff)
Batoe Besi
Greisen Nest
1:50

FIGS. 8, 9, 10.

lateritic ores on the savannahs in Surinam. As other influences are out of the question, the magnetite must have been produced by the action of the atmosphere and the sun. The fact that octahedrons of magnetite were found in vugs of the Seloemar outcrop, as well as in the Garoemedang lode, points to the primary nature of such crystals.

As one walks from the mouth of the uppermost tunnel in a southeasterly direction, the gossan disappears, and for 300 m. the vein in soft sandstone consists of stringers of white quartz some of which contain tinstone. Only at a depth of 4 or 5 m. a pale red color appears, which lower down passes into limonite-brown. A little farther on, a rich part of the vein has been worked as an open quarry. The ore body consisted chiefly of oxides but pyrite was not absent. Still farther along large boulders of ironstone lie along the footpath, indicating an unexplored and disintegrated outcrop of the vein. In the coastal plain, traces can be seen of an old working on the most easterly part of the Seloemar vein, which here possessed a limonite outcrop merging, not far below, into pyrite with a little tinstone. The distance from this spot to the Seloemar hill is about 3500 m.

The inconstancy in character of the broad fault veins on and just below the surface is also clearly visible in the Mangkoebang vein referred to before, a little south of the Garoemedang vein. Two parts of it, Mangkoebang and Antoe, proved to be nearly free from pyrite to a depth of 40 m., whereas a little farther west in a third part, pyrite was prevalent at a depth of 27 m.

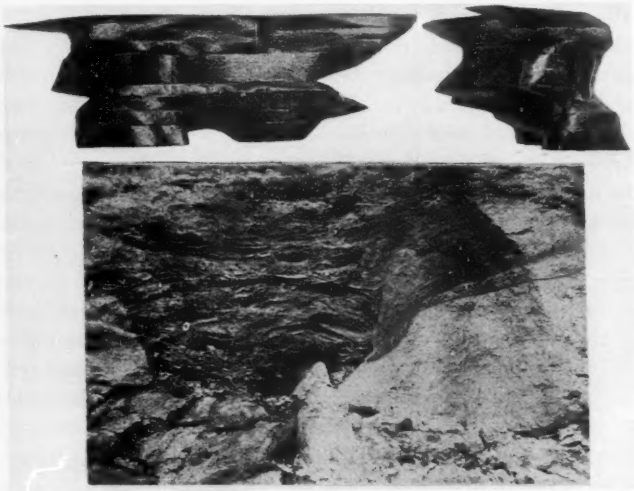
This feature may be explained by assuming that the sulphides, being later than the quartz-tinstone, were checked at narrow passages in the fissures, which had already been filled up, and that they could rise only where sufficient space was available.

In southeastern Billiton several more outcrops or rows of boulders of magnetite are found, which still await prospecting, but undoubtedly point to veins containing tinstone. Great boulders of magnetite have also been found in the district of Koba, Banca (Verbeek, *loc. cit.*, p. 47).

Ore in Quartz Bodies in Granite.—In every tinstone area nu-

merous reefs or dikes are found with a filling of white vein quartz, commonly with crystals, nests, or veinlets of cassiterite, rarely with tourmaline or wolframite. Generally, they are narrow, and fragments of them are commonly found in the kaksa and koolits. Evidently they belong to the vein zones. They also occur, however, apparently independently of tinstone, in which case they are barren and attain widths of from 5 to 7 m. From this it may be concluded that shortly after the gaseous emanations had passed, colloidal silica solutions, with or without mineralizing agencies,

11



12

FIGS. 11, 12. Photographs of a model of the quartz body of Tikoes, Billiton, between the levels III and IV, as seen from the north (Fig. 11) and from the east (Fig. 12).

FIG. 13. Infilling, with bed of mentjang ore, in a temporary valley cut in clayey overburden. Dabo valley, Singkep (After Wilhelm).

and belonging to the pneumatolytic-pegmatitic stage, invaded some of the fissures. They might be considered to be the counterparts of the feldspar dikes previously mentioned.

The Tikoes granite-hill in northwest Billiton, about 40 m. high,

and its surroundings, were known of old to be very rich; and the koolits were numerous. In 1910 a Chinese party discovered a cassiterite-wolframite occurrence in what was looked upon as an irregularly-shaped quartz lens in the midst of kaolinized granite. This gave an impetus to further prospecting. Finally, a shaft was sunk to a depth of 110 m., from which four levels were driven. On level I (30 m.) the lens was encountered. Fig. 9 shows the outlines of the quartz body on the 4 levels. Experience in this field is insufficient to decide whether these sections belong to a single body or not, but if there are two bodies, they must be connected.

Mining was started from level IV and, at the time of my visit, had not reached up to level III. The curious form of the quartz body having attracted attention, it was modelled to scale, and from this model the photographs shown in Figs. 11 and 12 were taken. The space occupied by the quartz suggests a complex set of small downthrows and saggings in the granite, and it may reasonably be assumed that the silica was forced up in magmatic colloidal solution.

Dr. Groothoff, to whom only level I and part of level II were known, made a study of this ore occurrence.[53] The quartz body lies in the midst of a coarse biotite granite with numerous aplite veins that vary in width from a few millimeters to some meters. Also, the quartz encloses many large or small granite fragments lacking signs of metamorphism, and streaks of aplitic material, which, in places, contains veins of quartz.

The chief constituent of the body, the quartz, occurs in large, cracked masses with a glassy aspect, which rarely show any trace of crystal outlines. When a lump of this quartz is smashed, it breaks into angular, razor-edged pieces. Its color is in the main bluish-white, but there are many grey patches with fading contours. The quartz is curiously semi-translucent owing to accumulations of minute inclusions of liquid and gas; a chemical test revealed that the liquid is nearly exclusively water, whereas the gas is composed of CO_2 with traces of Cl and H_2S. The grey

[53] *Op. cit.* (1916), p. 6.

color of the patches is due to very fine sulphides. Etch-tests evidenced that for the greater part the quartz belongs to the β-type, the balance having formed at a temperature below 575° C.

The quartz body includes, in places, solitary crystals or fairly large nests and aggregates of cassiterite and wolframite; the latter is commonly idiomorphic except at the extremities of the crystals. Their distribution is far from uniform and in the northeastern part of the mined quartz, ores were lacking. Chemically, the wolframite belongs to the usual mixed type. The tinstone is as a rule dark brown and contains both Fe and Mn; also the mineral occurs in paler colors, and zonal coloring is fairly common. Evidently the two ores were deposited almost simultaneously. Moreover, their crystals are commonly cracked and the cracks are filled with quartz or—rarely—with sulphides. The latter, *viz.* arsenopyrite, pyrite, galena, and sphalerite, however, occur mostly as fillings of cracks in the quartz. Topaz and fluor-lithia mica are chiefly confined to the border zone. Although wolframite and cassiterite are pneumatolytic minerals, the presence of the sulphides bears evidence of subsequent hydrothermal activity, which is also proved by the occurrence of scheelite, which is molded upon wolframite.

The kaolinization of the granite was less common on level II than on level I, and I did not observe it anywhere on the deeper levels. The quartz body, on the other hand, is largely surrounded by zones of greisen, but their distribution is so irregular that the act of greisenization has undoubtedly nothing to do with the formation of the quartz body. This is demonstrated by the cross-section at level I (Fig. 8). Under the microscope the junction of quartz and granite proves to be indistinctly defined, but the alteration brought about in the granite extends over a width of only a few millimeters and is insignificant. The exact extent of the greisen on the lower levels has not been mapped. Many granite remnants are enclosed in the greisen, both rocks merging into one another, especially where the greisenization was not fully effective and has only partially converted the feldspar.

The Tikoes greisen is fairly rich in pyrite and arsenopyrite,

but tourmaline is absent. The unweathered greisen is hard and contains many vugs; the minute particles of pyrite, however, soon weather and this causes the rock to crumble. Especially in the upper levels the greisen contains much topaz, commonly well-crystallized. Wolframite is scarce, but cassiterite particles are found in every sample.

Dr. Groothoff assumed that the parent magma was supersaturated with silica, and that from the initial phase of crystallization, separation of this excess of silica took place, which retained gaseous compounds of Sn and Wo in the presence of water. This silica—a product *in situ*—afterwards congealed and in the meantime oxides of these metals separated out as large-sized minerals of the first period. In the sequel the real pneumatolytic and hydrothermal agencies deposited the minerals of the second period in the cracks of the quartz and in the fissures of the granite, at the same time converting the latter into greisen.

The present writer cannot agree with this assumption, (1) because the Tikoes granite evidently belongs to the older kind of rock, which was not a carrier of ores; (2) because the irregular distribution of the ores of the first period is difficult to account for by such a solution; (3) because it can be taken for granted that the sequence of the magmatic residuals, as described in preceding pages, must have been the same everywhere in the islands.

The Tikoes occurrence may, therefore, best be explained as follows: The quartz body may be only an accidental variation of the broad barren quartz dikes from the pegmatitic stage, mentioned above; a fissure probably communicated with the empty space formed near the surface by crustal movements. The bulk of the pneumatolytic emanations chose the easy way through that space; the concentration of the gases was great, but the diminution of the temperature proceeded slowly, hence the generation of large ore mineral individuals which, just as elsewhere, were in the main deposited against the rows of quartz crystals that lined the walls. Most of the ore came to rest near the surface; the small lens mined by the Chinese was richer than the large quartz body. The balance of the gases followed the shearing zones and other fissures in the granite, with the usual consequences.

Subsequently the colloidal silica as a nearly dry melt with a temperature well over 600° C., was forced up through the fissure into the space. The quartz, which supported the ores, was softened and partly molten; the ores loosened, and were distributed at random in the viscous mass. The sudden rise of temperature caused many crystals to crack, but the wounds were immediately healed by silica.

Spontaneous crystallization of the quartz was hampered by the extreme viscosity; the ultimate solidification gave rise to contraction cracks. At the outset the dry melt contained, besides silica, a certain amount of other substances; the magmatic differentiation of the mass resulted in the separation of aplite streaks. The main entrance being blocked up for the greater part, only an unimportant quantity of the hydrothermal substances could ascend, probably mostly along the plane of contact with the granite, through which they could enter the greisen. In the quartz body itself they could only enter the cracks. The gases that filled up the formerly empty space, were under a fairly high pressure; a portion of them penetrated into the soft porous old granite above the space, and here a greisen area of considerable extent was generated, which formed rich koolits.

Tikoes was closed long before all the quartz had been mined. Only a few months after my departure, a large mass of mud and water that had filled up an old Chinese kollong, broke through, and flooded all the levels in the mine within ten minutes; 33 workmen were drowned. At the time of this disaster, the tin price was so low that mining in Tikoes was unprofitable, and it was decided to abandon the mine.

The amount of wolframite in the quartz of Tikoes is conspicuous but it rarely occurs in the greisen. Evidently this mineral is one of the first products of pneumatolysis. At a short distance south of Tikoes, however, wolframite has been found neither in the koolits, nor in the kaksa of the Raya river, and there are no other records of its occurrence in this kind of deposit in Banca or the rest of Billiton. As it is not likely that the mineral should have been entirely lacking everywhere, it has probably been at-

tacked by the humic acid of the water and carried away. The frequently reported occurrence in Banca of pyrolusite, polianite, and wad, points in this direction; in this island the parent mineral is exceedingly rare.

Ore in Greisen.—It has been mentioned on a preceding page that the mining of greisen at Tikoes was disappointing. Hydraulicking of the fairly extensive greisen fields on the Kandis hills, eastern Billiton, gave somewhat better returns, but, broadly speaking, where the rich greisen koolits were stripped off by the Chinese, what was left in the solid rock is of only moderate value.

It has also been mentioned that in the Tikoes greisen tourmaline is absent, whereas topaz is fairly abundant. At Batoe Besi tourmaline is common and topaz is not rare. Several tough aggregates of these minerals, mostly with quartz and cassiterite, which had been thrown away by the koolit-working Chinese, were collected and described by Dr. Groothoff.[54] Wolframite is not lacking in the greisen, but its quantity is small.

Dr. Groothoff found at Batoe Besi that the intensity of greisenization of the soft granite commonly varied greatly within a short distance, as is demonstrated in Fig. 10, so that the expression "greisen-nests" is more appropriate. The same feature was observed later near Tikoes; the nests here were of a purplish color, and they were so numerous that a thick slice of the granite was treated by hydraulicking; here, as elsewhere, however, the result was not favorable.

Surely, the greisenization of the old Banca granite must have been much more abundant than was formerly supposed, and this greisen has had its share in the formation of the rich koolit and kaksa deposits. Separate masses of greisen, such as those of Tikoes, however, are not known, neither are quartz bodies, although some may yet be discovered.

RIJSWIJK,
HOLLAND,
Dec., 1936.

[54] *Op. cit.*, vol. 4a, p. 333; vol. 4b, pp. 93–104.

DISCUSSION AND COMMUNICATIONS

THE ANNOTATED BIBLIOGRAPHY OF ECONOMIC GEOLOGY.

Sir: Your editorial concerning the *Annotated Bibliography of Economic Geology* was most timely. Although the immediate financial needs have been met by generous gifts from the Geological Society of America, the A. A. P. G., the Publishing Company, the National Research Council, and a number of good friends, as well as from the sponsoring Society, the ultimate success of the Bibliography depends upon whether or not it is adequately supported by the professional group that it is designed to serve. Thus far, the subscription list seems surprisingly small, which makes one fear that the unique value of the Bibliography is not yet properly appreciated, particularly by those who need it most, viz., the geologists engrossed in the exacting and immediate demands of commercial work. To keep abreast of the literature even in a special field is an almost impossible task under these conditions; yet one must do so or run the danger of falling so far behind in current scientific thought that his standing as a geologist is weakened and the quality of the professional service he is capable of giving is impaired. The bibliography provides a means of rapidly searching the literature, and making a critical selection of pertinent contributions to which the few hours available can be devoted.

The need for the Bibliography cannot be doubted; but a longer subscription list would be very welcome assurance to Professor Lindgren and his associated workers that the time spent in the arduous task of collecting titles and preparing abstracts is valued by the profession at large.

DONALD MCLAUGHLIN.

HARVARD UNIVERSITY.

Sir: Just a word of appreciation of the fine editorial on the *Annotated Bibliography*. The bibliography is all it says and more. We consider it indispensable in the Survey library. Each number is carefully checked and reference cards are made of those abstracts for which we have more or less reference use.

ARTHUR BEVAN.

STATE GEOLOGIST, UNIVERSITY, VIRGINIA.

Sir: It should give satisfaction to all economic geologists to note your editorial commending the *Annotated Bibliography*. It is surprising that all economic geologists have not availed themselves more generally of this excellent "short cut." The profusion of printed pages forces the investigator either to be buried, or to use such a short cut to save his eyes—and his mind! In other fields, such as chemistry, the value of systematic abstracts has been recognized and actively supported for decades. What chemist would regard his library as complete without the invaluable "Chemical Abstracts"?

Most surprising, perhaps, is the lack of appreciation among the mining and petroleum companies. It is safe to say that no more important event in the realm of publications has taken place, since the founding of ECONOMIC GEOLOGY, than the initiation in 1929 of the bibliography. Its advent marked a broadening of our interests because it broadened and internationalized our knowledge. It is the only available list in English of foreign economic titles. At twice the cost such a list alone would be invaluable, even without the terse condensation and sapient comments that accompany its titles. Many organizations that cannot afford a long list of journals will find this a highly serviceable and inexpensive substitute.

It seems a pity that this useful tool has been so frequently neglected, so generally forced to beg for alms at the hands of a partly unappreciative audience. And it is to be hoped that consulting geologists, staff geologists, and all workers in the field of applied geology will do what they can to remedy the situation.

CHAS. H. BEHRE, JR.

NORTHWESTERN UNIVERSITY.

REVIEWS

Interpretative Petrology of the Igneous Rocks. By H. L. ALLING. Pp. 353., pls. XI, figs. 48. McGraw-Hill Book Co., Inc., New York, 1936. Price $4.00.

The first fifty-five pages of this book are a discussion of certain aspects of physical chemistry essential to an understanding of the nature and origin of igneous rocks and their minerals. The next eighty-six pages are used to present a discussion of the components and a compilation of graphs showing the degree of mutual solubility for the components, the relationship of optical and physical properties to composition, and the phase-equilibrium diagrams for each of the major mineral groups of igneous rocks. The major part of the book (196 pages) comprises a series of chapters on certain problems of igneous rocks, such as Zoned Crystals, Order of Crystallization and Intergrowths, Hyperfusible Constituents, Homogeneous Equilibria, Crystallization of Magmas, Diversification of Igneous Rocks, Magmatic Assimilation, Final Consolidation of Igneous Rocks, Garnet Reaction Rims, Petrographic Provinces and Comagmatic Regions, Origin of Igneous Rocks, Mode versus Norm, Grain Size, and a final chapter on Interpretative Petrology.

The author in the preface states that there is no suitable textbook for students presenting phase-rule chemistry as applied to rocks which is simple enough for them, and that he has attempted to supply this need. The reviewer has for a number of years endeavored to teach students in geology the interpretation of phase-equilibrium diagrams and their significance for petrologic problems. If this experience affords any criteria, the discussion of this subject in the book under review is so condensed that it will prove quite inadequate. In one case (p. 12) the author has apparently confused what may be learned from the interpretation of a phase-equilibrium diagram for a system which has already been worked out experimentally with what may be predicted beforehand by means of the phase rule alone. The discussion of the ternary diagrams on pages 214–216 are marred by certain inaccurate statements.

The section on the thermal, optical, and physical relationships of each of the mineral groups is quite up to date and most excellent for the unified picture it enables one to get provided one brings to it a certain previous familiarity with the subject. A question may well be raised as

to the appropriateness of the phase-equilibrium diagram (Fig. 19) given for $MgSiO_3$–$CaSiO_3$, and W. T. Schaller, rather than Winchell, should have been credited with naming the mineral johannsenite (p. 90).

The chapters on the problems connected with igneous rocks are for the most part of the nature of reviews of the literature with all points of view presented, written in the spirit of critical essays and in general with the exercise of well-balanced judgment.

The chapters on hyperfusible constituents and homogeneous equilibria are largely after P. Niggli. In the chapter on hyperfusible constituents a mistake has been made in copying Fig. C, p. 176, where liquid should read gas (or vapor); and the significance of the series of diagrams has not been helped by retaining from the original the notation (silicate) to indicate the presence of this phase in only one case. The sentence (p. 179) "It is conceivable that, if it possessed a high saturation pressure, it would exist as a fluid, if a low saturation pressure, it would exist as a gas" also needs clarification.

Several examples of the misapplication or misquotation of Bowen's ideas on the reaction principle as applied to problems of assimilation are present in the geologic literature. An additional one is here (p. 246) added where there is ascribed to Bowen a belief that "Magmas dissolve minerals of inclusions that are higher in the reaction series rather than the minerals of a magma with which it is in equilibrium."

In the chapter on garnet reaction rims, a most detailed explanation is given of the manner in which the hypothesis of peritectic reaction might apply, and only passing mention is made of the hypothesis of essentially regional metamorphism so ably presented by Sederholm.

The reviewer would have liked to see the significance of the principle of chilling, as applied to the study of the course of crystallization of a single rock or a series of rocks of similar bulk chemical composition but different degrees of crystallization, discussed at greater length in a book of this title.

The subject matter of the book in general is of such a character and is treated in such fashion that it serves to supplement rather than duplicate other books now available on the petrology of igneous rocks. On the whole it appears to be dependable, the errors cited being no more in number than those often present in many new books. The author has exceptional capacity for presenting complex relationships in tables and graphs in such a fashion that they are readily understood, and the book should be of value to those who, with some previous knowledge of the subject, desire to get a broad and up to the minute survey of many major problems of the petrology of igneous rocks and their minerals.

A. F. BUDDINGTON.

PRINCETON UNIVERSITY,
Princeton, N. J.

Great Earthquakes. By CHAS. DAVISON. Pp. xii + 286, pl. 12, figs. 97. Thos. Murby & Co., London 1936. Cloth 5½ × 8½. Price 17s 6d.

The author describes in great detail the phenomena attending eighteen of the greatest earthquakes that have occurred during the past two centuries. A nineteenth was discussed in his book "The Japanese Earthquake of 1923" (this Journal, Vol. 26, p. 675). In his Preface he states that the earthquakes described "have been chosen not only for their magnitude and destructive power, but chiefly for the light that they throw on the nature and origin of great earthquakes, and because, in every case, very careful studies have been made of the phenomena that accompanied and followed them."

The eighteen quakes selected for description are the Lisbon, Calabria, New Madrid, Cutch, Valparaiso (2), Conception, Owens Valley, Mino-Owari, Sanriku (2), Assam, Alaska, California, Messina, Tango, Idu and Hawke's Bay. The book is a compendium of the results of studies by more than 200 geologists, well written and excellently illustrated by maps and 25 photographs. Naturally there can be little new information in it, but it will serve as a valuable and conveniently arranged collection of observations and inferences culled from widely distributed sources, some of which are difficult of access to those not near large libraries.

W. S. BAYLEY.

The Petroleum Times: "Principles and Pratical Results of Geophysics," Vol. (new series) 36, No. 916, August 1, 1936. Pages I to XLVIII and 141, 143, and 151; Figs. 22; Maps and Diagrams, 28.

This is an interesting short account of geophysical prospecting; its history, principal successes and world use. The authorship is anonymous but seemingly must lie close to the Schlumberger organization. Both educated layman and professional geophysicist will read it with interest. It comprises a short history of geophysical prospecting; extracts from a lecture by Conrad Schlumberger on the "Present Position as to the Geophysical Methods," exploration of drill holes, a brief statement of the technique of magnetic, gravimetric and resistivity methods, application of the resistivity method in the Alsatian potash basin, and in the Baker district, seismic method, world wide use and success of the geophysical methods of prospecting and the more important geophysical companies of the world.

A point of interest in the statistics is the great importance the U. S. S. R. places on surface electrical prospecting, 23 surface electrical parties against 5 seismic parties; for Roumania 2 surface electrical parties are

listed against 1 each for the seismic and gravimetric methods, although for the world as a whole, 35 surface electrical parties are listed against 110 seismic (figures much too low for the United States) and 74 gravimetric.

The survey of the world use of geophysical prospecting and the maps showing the areas covered in North America, Roumania, North Africa, and the U. S. S. R. are particularly interesting.

DONALD C. BARTON.

HOUSTON, TEXAS.

The Geology of the Organ Mountains. By K. C. DUNHAM. State Bureau of Mines & Mineral Resources (N. Mex.), Bull. No. 11. Pp. 272, Pl. 14, Figs. 21. Socorro, New Mexico, 1935. Price $1.00.

Deals with the geology of the Organ Mountains in Dona Ana County. The mountains consist mainly of a great batholite of granite cut by epidorite dikes, upon which is deposited a series of paleozoic rocks, that were uplifted at the end of Cretaceous time and covered with rhyolites, andesites and basalts. Later a great mass of monzonite cut this complex, metamorphosed the invaded rocks and gave rise to the ore deposits of the region. The greater part of the volume discusses the nature and origin of these deposits and describes the individual mines.

Engineering Geology. By H. RIES AND T. L. WATSON. 5th Ed. Pp. 750, figs. 271. Wiley & Sons, 1936. Price $5.00.

This volume is equivalent to six textbooks, abridged and condensed into one—namely one each on: minerals, 45 pages; rocks, 108 pages; structural geology, 63 pages; general geology, 267 pages; economic geology, 202 pages; and a brief one of 46 pages on historical geology. The part on general geology resembles most texts except that emphasis is placed on engineering phases, more space is devoted to subsurface water, and there is a chapter on the geology of Reservoir and Dam Sites. The part on economic geology is essentially a condensation of the authors' texts on economic geology.

The scope of the book is the same as in previous editions but considerable revision is noted, and the material has been brought up to date.

Although a heavy dose for a single course, the student who digests the material of this book will know much about the several branches of geology.

BOOKS RECEIVED.

J. D. BATEMAN.

Magnetometric and Gravimetric Surveys in the Transvaal. O. WEISS, D. J. SIMPSON AND G. L. PAVER. Pp. 27, maps 9. Union of S. A. Geol. Surv. Div., Bull. No. 7., 1936. Price 2/-. Successful location and delineation of nickel ore pipes with the Torsion Balance, and application of the gravimetric method of determining ore possibilities beneath unproved gossans.

Ann. Rept. Quebec Bur. of Mines, 1934. Part D. 1935. Dartmouth River Map Area, Gaspé Peninsula. I. W. Jones. Pp. 42, pls. 3, map. Cambrian to middle Devonian; petroleum, lead and zinc, asbestos and chromite, copper, gold and silver, iron; The Paleozoic of the Deschambault Region, Portneuf County. Abbé J. W. Laverdière. Pp. 18, pls. 3; Mount Megantic Area, Southeastern Quebec, and its Placer Gold Deposits. H. W. McGerrigle. Pp. 40, maps 1. Gold, silver, copper, pyrite, asbestos, building stone, and gravel.

Some Geological Relations Between the Constitution of Soil Materials and Highway Construction. G. E. EKBLAW AND R. E. GRIM. Pp. 16, figs. 4. Ill. Geol. Surv. No. 42, 1936. Price, 25 cts. Mineral constitution of soil materials affects their properties and must be determined before their physical reactions under various conditions may be predicted.

West Half of Wildcat Hills Map-Area, Alberta. G. S. HUME. Pp. 15, figs. 2, pls. 2, maps, 2. Can. Dept. of Mines, Geol. Surv., Mem. 188, 1936. Price, 10 cts. Oil and gas possibilities in lower and upper Cretaceous.

Soil Survey of Craig County, Okla. A. C. ANDERSON, A. W. GOKE, O. H. BRENSING, R. E. PENN AND C. B. BOATRIGHT. Pp. 41, map. U. S. Bur. of Chem. and Soils, Ser. 1931, No. 24. Price 35 cts.

Soil Survey of Nansemond County, Va. R. E. DEVEREUX, E. SHULKCUM AND G. W. PATTESON. Pp. 39, pls. 2, map. U. S. Bur. of Chem. and Soils, Ser. 1932, No. 6. Price 30 cts.

Publications on the Geology, Mineral Resources and Mineral Industries of Illinois. Pp. 95. Ill. Geol. Surv., Urbana, 1936.

Oil and Gas Development in Illinois in 1935. A. H. BELL. Pp. 15. Ill. Geol. Surv. No. 28. 1936. Statistical data.

Geology and Oil Possibilities of the Illinois Basin. J. M. WELLER. Pp. 19, figs. 9. Ill. Geol. Surv. No. 27. 1936. Stratigraphy, structural history and oil and gas occurrences.

Mineral Production, Province of Quebec for 1935. Pp. 11. Bur. of Mines, Pub. 110, 1936. 1935 production increased 24 per cent over 1934.

International Geological Congress. Report of the XVI Session. U. S. A. 1933. Washington, 1936. 2 vol. Pp. 1311. Numerous plates, maps and diagrams illustrating a variety of papers. A valuable contribution to geological literature.

Rochas Oleigenas do Brasil. S. F. ABREU. Pp. 159, pls. 10. Inst. Nac. de Tech. Rio de Janeiro, 1936. Occurrence and utilization of oil shale in Brazil; although commercial profits may be small, the presence of oil shales is considered a factor in national defence.

Reconhecimento Geologico Nos Rios, Tocantins e Araguaya. A. LÖFGREN. Pp. 60, pls. 15, maps 3. Serv. Geol. e Mineral. Bull. 80. Rio de Janeiro, 1936. Results of geological traverses.

Algumas Jazidas de Minerios de Chumbo do Estado de Minas Geraes. B. A. WENDEBORN. Pp. 47, figs. 11. Serv. Geol. e Mineral. Rio de Janeiro, 1935. Lead ore occurrences in limestone.

La Región Aurífera de Marcapata, J. F. A. REVOREDO, and **Estudios en Los Lavaderos Auríferos de Los Ríos Pachitea y Napo.** L. F. AGUILAR. Pp. 117, pls. 14, maps 4. Bol. del Cuerpo de Ingenieros de Minas del Peru. No. 116. Lima, 1936. Lode and placer gold occurrences.

Bull. Geotechnical Comm. Govt. Rys. of Japan. No. 4. Pp. 268, figs. 74, pls. 27. 1936. Statistical data and one excellent paper dealing with the consolidation of sediments and their mechanical and mineralogical properties. Printed in Japanese and English.

Marble Deposits of Canada Bay and White Bay, Northern Newfoundland. G. W. BAIN. Pp. 7. Nfd. Geol. Sect. 1936. Survey resulting from interest in unworked marble deposits owing to disrupted European marble trade because of sanctions against Italy; some deposits of limited commercial importance.

Ann. Rep. Geol. Surv. Dept. Uganda Protectorate. Pp. 19. 1936. Price 2/–. Notes on occurrence of gold, silver-lead, tinstone, beryl, bismuth, columbite-tantalite, asbestos, wolfram and thermal springs.

German-English Geological Terminology. A. CISSARZ AND WM. R. JONES. Pp. 250. Thos. Murby, London, and Van Nostrand, New York. Price $5.00. Invaluable to those who wish to learn or brush up on geological German. Left hand pages are in English, right hand in German. Covers all phases of geology; appendices on abbreviations, tables, and chemical and mineral names; index.

SOCIETY OF ECONOMIC GEOLOGISTS

Abstracts of papers presented at the Seventeenth Annual Meeting, in conjunction with the American Institute of Mining and Metallurgical Engineers, New York, Feb. 16–17, 1937.

*ALUNITE DEPOSITS OF THE MARYSVALE REGION, UTAH.**

EUGENE CALLAGHAN.

The alunite deposits in the western High Plateaus of Utah are restricted to Tertiary volcanic rocks, which lie upon Wasatch and older sediments, and which are overlain by a sedimentary formation tentatively called the Sevier River. There are two types of deposits—replacement and vein. The replacements are chiefly altered volcanic rock with variable proportions of alunite, some of which is sodic; impurities are abundant. Deposits of the vein type are mostly coarsely crystalline and much purer than those of the replacement type. Though there is evidently considerable alunite of both types in the region, work done thus far does not justify revision of earlier estimates of reserves.

*THE NEGLECTED MINE, LA PLATA DISTRICT, COLORADO.**

E. B. ECKEL AND F. W. GALBRAITH.

The Neglected mine, which has produced over $500,000 in gold and silver, shows a close relationship between a telluride vein and a dikelike mass of porphyry. The country rocks are low dipping unaltered red shales and arkosic sandstones, which are cut by a tabular body of monzonite porphyry that trends east-west, and dips south, and pitches easterly.

The Neglected vein parallels the porphyry and in places cuts it; elsewhere it follows either contact with the sedimentary beds. The wall rocks of the dike are strongly altered; beyond its limits the alteration zone is thin or absent. Similarly, the vein is stronger and more persistent near the dike. Nearly all the ore has come from a single ore shoot, which closely parallels the dike and also pitches eastward. Since the dike extends downward below the lowest, or 175-foot level, the possibility of downward extension of the ore shoot appears worthy of exploration.

* Indicates that abstract is published by permission of the Director, United States Geological Survey.

TEXTURAL RELATIONS IN B. C. GOLD ORES.

HARRY V. WARREN AND JOHN M. CUMMINGS.

The authors present a mineralogical classification of British Columbian gold ores and show how this classification, when used in conjunction with mineralographic studies on a particular ore, can be of value in attacking milling problems. Various mineralogical factors that influence the concentration of gold in ore bodies are discussed. The paper also puts forward what is believed to be a new idea in proposing that the relationship between gold and various minerals in a particular ore may be correlated with the vertical range through which a gold ore may be expected to persist, other factors of course remaining equal.

*SOME MINERAL DEPOSITS OF THE GLACIER BAY REGION, ALASKA.**

JOHN C. REED.

Prospecting in the Glacier Bay National Monument has been confined so far to granitic rocks near contacts with Paleozoic sediments, which they intrude.

Near Reid Glacier thin veins, a few of which are traceable for about 300 feet both horizontally and vertically, trend northerly and carry sphalerite, galena, and pyrite. Gold was panned from some of the better looking material.

Near Sandy Cove, 30 miles away, more irregular, but locally thicker, veins appear to carry only pyrite. Here pyrite also occurs along the contact between the granitic rocks and the intruded limestone.

Sparse ore minerals have been seen at other places in and near the monument. As yet, no large mineral deposits have been found there, but many miles of igneous contacts have not been prospected. In southeastern Alaska, as elsewhere, such contacts are considered favorable places in which to search for mineral deposits.

*THE ORIGIN OF THE BULL VALLEY, UTAH, IRON ORE DEPOSITS.**

FRANCIS G. WELLS.

The iron ore deposits of the Bull Valley and Iron Springs districts, Utah, consist of veins of magnetite and hematite in monzonite, and magnetite-hematite replacement bodies in limestone. Neither ores nor country rock show features characteristic of contact metamorphic deposits. The following explanation of the origin of the deposits is offered. During

the intrusion of monzonite porphyry stocks, the hoods and overlying rock were fractured, causing a sudden release of pressure and liberating $FeCl_3$ and H_2O gas from the stocks which were still at high temperature. These gases found ready egress to the surface along tension fissures without appreciably heating the country rock. They deposited magnetite and hematite in the fissures and replaced the contiguous fractured limestone. The period of gas emanation was brief and the hydrothermal phase probably evolved during the later magmatic history never reached this area. The deposits were formed under a cover of less than 5,000 feet.

*THE TYPES OF COAL.**

TAISIA STADNICHENKO.

The widely used terms of "type," "rank," and "grade" of coal are not very clearly differentiated, and various authors often give them either overlapping or contradictory meaning. The conception of "type" as developed by members of the U. S. Geological Survey is based primarily on the characteristics of the ingredient plant material and the physical and chemical composition of the organic sediment at the cessation of the peat stage of coal formation. The purity of the grade of coal depends on the amount of the inorganic material laid down with the organic substances. The primary characteristics of the "type" are never totally obliterated by the subsequent geodynamic changes and are still recognizable in higher ranks of coal including anthracites.

THE GEOLOGY OF DAM SITES OF THE TENNESSEE VALLEY REGION.[1]

E. C. ECKEL, E. L. SPAIN, JR., AND ROGER F. RHOADES.

Eastern Region: The eastern portion of this area lies in the Appalachian province of highly metamorphosed arkoses, graywackes, schists, and slates. Two high storage dams are proposed and both sites are upon hard graywacke. The soundness of the rock leaves few difficulties, but a deeply weathered fault and several shear zones demand special treatment at one location.

The western part is embraced by the folded and faulted limestones, dolomites, and shales of the Valley and Ridge Province. The natural susceptibility of these rocks to groundwater solution is increased by abundant faulting and tilting of strata, which also is responsible for deep artesian circulation.

The difficulties encountered in such a region are exemplified by Chickamauga dam site at Chattanooga, Tenn. The axis crosses just below a fault whereby the Knox dolomite has been thrust over the Chickamauga

[1] A symposium on work done by the Tennessee Valley Authority.

limestone several thousand feet. The shattered rock has allowed free circulation to acid groundwater and solution cavities are numerous in the foundation.

Central Region: In the middle one third of its course, the Tennessee River traverses an area of flat-lying and undisturbed rock beds. Here the T. V. A. is constructing three dams and two others are already existent.

Since limestones and calcareous shales underlie the dams, the geological problems involve chiefly groundwater solution. If limestone beds are horizontal and artesian conditions therefore lacking, solution does not take place to a depth of more than thirty feet below the water table in the river.

Certain structural features such as bedding planes, shale layers, and vertical jointing are important primary control factors affecting the rate and direction of groundwater flow and therefore the orientation of solution cavities. Percolation through floodplains upon which earth-fill dams are laid receives consideration.

Geological problems of an engineering nature and their treatment are brought out in discussions of Pickwick, Wilson, Wheeler, Guntersville, and Hales Bar dams.

Western Region: This lies at the north-east edge of the Mississippi embayment and hence dam sites in this area may have one abutment in unconsolidated Cretaceous materials.

Formations of the Osage and Lower Meramec Groups constitute the bed-rock of the Tennessee River sites; those on contiguous portions of the Cumberland and Ohio rivers are members of the Upper Meramec and Chester Groups.

This section of the Ohio Valley is intricately faulted whereas, except near their mouths, the Tennessee and Cumberland valleys are traversed by fewer and more widely spaced faults.

In consequence of the buried channels of the lower courses of the Ohio and Tennessee rivers being over-steepened, the thickness of river alluvium varies greatly at the different sites. For example, fluviatile sediments are 130 feet thick at the Gilbertsville site (Tennessee River), 140 feet at the Cumberland River site, and exceed 250 feet at several places on the Ohio River.

*METHODS OF CONSTRUCTING BLOCK DIAGRAMS FOR USE IN MINING GEOLOGY.**

T. B. NOLAN AND W. D. JOHNSTON, JR.

In the past five years members of the Geological Survey have gained experience in making isometric block diagrams of mines and mining

districts as well as of surface features. This paper presents nothing new, but aims to assemble scattered information on a much neglected method of geological illustration. Plotting mine workings on isometric paper is the most exact method but is extremely time-consuming. For most purposes the use of some form of isometric pantograph greatly lessens the labor of constructing the diagram. The devices of Dufour, Bradley, and Van der Hoop are described.

THE STRUCTURAL ENVIRONMENT OF THE BENDIGO GOLDFIELD.

J. B. STONE.

A unified explanation of the local and regional structure of the Bendigo (Victoria) goldfield and of the localization of its gold-bearing quartz reefs (production 16,000,000 oz.) is attempted. It is held that the region yielded to continued compressive stresses, first by close folding of Lower Ordovician slates and sandstones, and later by reverse faulting (shearing) in the axial portions of the folds. The faulted axial portion of each anticline constituted an independent channelway and locus of deposition for ore solutions. Greatest intensity of faulting, and therefore most reefs, are found in related domes on several of the different anticlines. It is suggested that compression and faulting continued almost throughout the period of mineralization and that the reefs grew principally by repeated opening and deposition but with some replacement. The end of the period of compression and mineralization occurred before the intrusion of lamprophyre dikes that occupy tensional rifts coinciding roughly with the axial planes of the anticlines.

*THE SLUMBERING HILLS, NEVADA.**

F. C. CALKINS.

The recently discovered and much publicized gold deposit owned by the Austin brothers of Jungo, Nevada, lies in the northern part of the Slumbering Hills, about 30 miles northeast of Jungo. The chief country rock of the district is a moderately metamorphosed series of shales and sandstones, which is intruded by quartz monzonite a few miles south of the mine and overlapped by Tertiary lavas on the flanks of the hills. The most characteristic gangue mineral at the mine is adularia. Gold-bearing quartz veins resembling those of the Mother Lode occur on the east slope of the hills and yielded some production in former years.

GEOLOGY OF BUCHANS LEAD ZINC COPPER DEPOSITS, NEWFOUNDLAND.

P. W. GEORGE.

The paper presents geological data regarding deposits of over 7,500,000 tons of fine grained sulphide ore in barite gangue. Pyroclastic and arkose rocks are intruded by sills of quartz porphyry in connection with batholithic intrusions of granite three miles from Buchans. Gentle folding, with fracturing and shearing of tuff beds and intruded quartz porphyry, accompanied and followed the intrusion of granite and porphyry. The sulphide-barite mineralization is localized primarily in fractured and sheared tuff beds, but also in the sheared quartz porphyry. Two structures have proved particularly favorable for ore—one, the center of an anticline; the other, a series of weak, incompetent tuff beds intruded by thin sills of quartz porphyry and located between strong beds of arkose. During the folding the weak tuff with intruded quartz porphyry was intensely sheared and contorted and subsequently mineralized by sulphides and barite.

THE HUITZUCO MERCURY MINES, GUERRERO, MEXICO.

C. W. VAUPELL.

The Huitzuco Mines lie in north-central Guerrero, Mexico; production is about 90,000 flasks of quicksilver since 1873. Near-surface ores fill extinct mud-geysers and the deep deposits are chambered veins, stockworks in brecciated blocks, and replacements in limestone. The epigenetic minerals livingstonite, stibnite, and sulphur occur in limestone, gypsum and dolomite through a developed vertical range of 260 meters. The deepest workings expose an increased amount of stibnite, which probably indicates that the lower limit of mercury mineralization is being approached. A resurgence of heat and water formed geysers over an extended area after the period of mercury mineralization. Mud geysers, which are situated in the outcrops, contain secondary mercury minerals, cinnabar and barcenite in the gravel and mud filling the vents.

A 150 ton flotation plant is in operation concentrating stope fills that assay 3.0 kilos of mercury per ton. 150,000 tons are available in one open stope which is more than one hectare in area and 60 meters high.

*STRUCTURAL CONTROL OF THE ORE DEPOSITS AT TOMBSTONE, ARIZONA.**

B. S. BUTLER AND ELDRED D. WILSON.

The Tombstone district has yielded approximately $36,000,000 in precious and base metals from deposits localized by Laramide folds, faults, and fissures in Paleozoic and Mesozoic rocks.

Southeast-northwest folding, east-west faulting, and north-south faulting and fissuring culminated with intrusion of rhyolite-latite porphyry in the western portion of the district and of monzonite in the northern portion; monzonite dikes occupy many of the north-south faults. After the intrusions, northeast-southwest fissures formed the main ore channels. Their intersections with favorable structures and favorable rocks determined the location of the ore shoots. Hence there are deposits associated with (1) north-south (dike) fissures, as exemplified in the Contention and Grand Central mines, (2) faults (Lucky Cuss and Oregon mines), (3) anticlines (Empire and Toughnut mines) and (4) northeast-southwest fissures (West Side, Skip Shaft, and State of Maine mines).

SOME OF THE MAJOR STRUCTURAL FEATURES OF THE CANADIAN PRE-CAMBRIAN GOLD AREAS.

CHARLES SPEARMAN.

This paper aims at an interpretation of the following phases pertaining to Canadian pre-Cambrian gold deposits: (1) the segregation of gold deposits along certain well defined provinces; (2) the association of the gold deposits with the more or less "quartzless" types of igneous rocks; (3) the gradual increase in volume of the gold deposits with depth; (4) the different types of gold deposits, such as the Porcupine type, Kirkland Lake type, Northwestern Quebec type, and the anomalous type, all of which are presumed to emanate from underlying batholiths; (5) the granitic masses paralleling the above types of gold deposits; (6) the dimensions of the batholiths associated with the gold deposits, based upon the quantity of gold diffusion in the batholithic magma which is then recast in terms of magmatic volume; (7) the probable depth of the gold deposits.

SEDIMENTARY DEPOSITS OF COPPER, VANADIUM-URANIUM AND SILVER IN SOUTHWESTERN UNITED STATES.

RICHARD P. FISCHER.

Widely distributed deposits of copper ("Red Beds Type"), vanadium-uranium and silver, occurring in sandstones and shales of Permian, Triassic and Jurassic ages, exhibit many common features and are thought to have a similar origin. Chromium-bearing standstones of limited distribution belong to the same class. Mineralization, although mostly discontinuous, is recurrent at certain stratigraphic horizons. Commonly, the ore bodies are distinctly lenticular and in some cases it can be demon-

strated that mineralization was restricted to a particular lens. Chalcocite pseudomorphs after plant remains show undeformed cell structure, suggesting mineralization previous to deep burial. Geologic structures such as faults, folds, etc. appear to be post-mineralization and show no genetic relationship to ore deposition.

This evidence opposes current ideas of mineralization by circulating meteoric waters or ascending thermal solutions and it is believed that the concentration of the metals occurred at the time of deposition of the enclosing sediments.

NEW DATA ON THE WISCONSIN LEAD–ZINC DISTRICT.

CHAS. H. BEHRE, JR.

Continued modest operations have permitted reinvestigation of this district, yielding theories differing somewhat from earlier ones. Mineralogically the ores are rich in pyrite and wurtzite (?), now altered to sphalerite. Rhythmic variations, especially in iron content, occurred. The solutions became progressively acid. These, with recently described work on inclusions, give a reliable picture of the nature of the solutions. The new chemical and mineralogic data favor ascending, rather than descending water.

Structurally, conclusions regarding the relations between ores and basin flanks were confirmed by new data covering four square miles near Hazel Green. Brittle dolomites are the most favorable host rocks and the ores are clearly fracture fillings. Several mineralized faults (both "beddings" and transecting faults) were recognized. Their displacements were slight but not generally measurable. Structural evidence favors mineralization by descending waters ponded in synclines, or ascending waters ponded in deeper parts of folds, but not artesian waters.

GEOLOGICAL RELATIONS OF SOME MAJOR GOLD DEPOSITS OF THE CANADIAN SHIELD.

E. L. BRUCE.

The geological relations of some of the chief gold deposits of the Canadian shield are summarized. Most of them are lodes made up of quartz veins in which metallic minerals are not abundant. They occur in ancient lavas, sediments, and intrusive rocks such as granodiorite. The minerals present indicate deep seated conditions and a magmatic source for the ore-bearing solutions. In few cases can igneous rocks outcropping in the vicinity be shown to be genetically related to the ores. In

some occurrences the veins are clearly much later than any neighbouring intrusive. It is suggested that proximity of ore bodies to exposed masses of igneous rocks is entirely due to structural control and that any intrusives that are directly related to the ore solutions lie deep below the surface.

ORE DEPOSITS OF THE SUNLIGHT MINING REGION, PARK COUNTY, WYOMING.

W. H. PARSONS.

(Read by Title.)

The Sunlight Mining Region lies in Wyoming in the northern Absaroka Mountains, Wyo. The deposits occur above timberline in a rough mountainous country twenty miles from the nearest road and are not developed. The mineralization is genetically associated with an intrusive and volcanic center which is characterized by a small stock of syenite and diorite, several basaltic plugs, hundreds of radially-arranged dikes, and a few cone sheets, all in the Early Basic Breccia Series of the Absarokas. The deposits occur as small, irregular fissure veins in fault zones and along dike contacts in the Tertiary Volcanic breccias.

The common ore minerals are pyrite, chalcopyrite, galena, and tetrahedrite with pockety values in gold and silver. The gangue is essentially various carbonates and quartz. The deposits have the banded and vuggy character of typical epithermal veins. The various deposits exhibit a vertical zoning that is well exposed due to the 3,000 foot relief, and seems to have been dependent on a vertical temperature gradient that existed in the roots of the volcano shortly after its activity had ceased. In the deepest zone are pyrite-quartz veins and above them successively, chalcopyrite-pyrite-gold, chalcopyrite, galena, and galena-silver veins in a 2,000 foot range.

THE AIRPLANE AIDS ALASKAN MINING.

E. N. PATTY.

This paper emphasizes the rise of airplane transportation in Alaska. Landing fields are numerous. Fairbanks is the flying center in interior Alaska, and Juneau the point of entrance. One Juneau company operates twin-motored ships cruising at 180 miles per hour. In summer, planes with floats are used, but the floats reduce the loads. Small models are in considerable use, but larger several-motored ones carry most freightage. Costs at present approximate 80 cents per ton mile. Machinery is dropped by Parachutes; food, in special packing. Especially favorable

is the saving of time effected by air service. Winter flying conditions are good. The private ownership of planes by mining companies is not favored because of the expenditures on special force and equipment and the irregularity in demand. So far, prospecting "from the air" has not been extensively developed, but may be expected to grow.

GEOLOGY OF THE TAXCO MINING DISTRICT, GUERRERO, MEXICO.

Y. S. BONILLAS.

This silver district, 110 kilometers south of Mexico City, has yielded perhaps 4,000,000 kilos of silver. It lies in an area of dominantly northwesterly ridges. The rocks are ancient schists, followed by andesites, shales, and limestones of uncertain age; above these are Cretaceous limestone, Tertiary clastics and flows, and late Tertiary rhyolites. Mineralization is related to coarse-grained porphyritic intrusions varying from rhyolite through monzonite to fairly basic andesite. These were intruded in the middle Tertiary, when extensive faulting and fracturing also took place—shortly after late Cretaceous close folding. At this time also the ores were deposited. The chief ore bodies and the most continuous ones are in the limestones. The chief ore minerals are argentite and ruby silver in the primary ores and cerargyrite and native silver in the secondary ores. With these are the usual base metal sulphides and gangue minerals, especially of lead and zinc. There is marked vertical zoning; quartz-calcite-silver veins change downward to quartz-pyrite-sphalerite-galena veins with declining values. The largest and richest ore bodies are at vein intersections.

SCIENTIFIC NOTES AND NEWS

Waldemar Lindgren was awarded the Wollaston Medal by the Geological Society of London, at the anniversary meeting of the Society on Feb. 19. The Wollaston Medal is "To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made." Some of the previous recipients of this award are Prof. G. A. F. Molengraaff, Sir John S. Flett, and J. H. L. Vogt.

H. Foster Bain has gone to Manila, via the "China Clipper," for about six months as adviser to the Philippine Government on mining matters. He is being assisted by Russell Fleming, mining engineer of Los Angeles.

Leslie L. Motz, of Bisbee, Ariz., is with the Eagle-Picher Mining & Smelting Co., at Tombstone, Ariz., engaged in engineering and geological reconnaissance.

William B. Maitland has gone to Manila, via the "China Clipper," where he is assistant superintendent and geologist of Crown Mines, Inc., Baguio, P. I.

Ernest W. Skeats of the University of Melbourne is on sabbatical leave and will visit shortly universities in the U. S. and then proceed to England and the International Geological Congress in Russia. Later he will visit the Anglo Iranian oil fields.

F. E. Keep, of South Africa, is on a business trip to Australia.

G. L. H. Loram, consulting geologist and mining engineer, is now in the Philippine Islands and can be addressed in care of Atkins, Kroll & Co., Manila, P. I.

E. B. Bailey, Professor of Geology in the University of Glasgow, has been appointed Director of the Geological Survey of Great Britain and Museum of Practical Geology. Professor Bailey served on the staff of the Geological Survey from 1902 until December 1929, when he resigned from his position of District Geologist on appointment as Professor at Glasgow.

C. Carleton Semple is now engaged by the San Luis Gold Mines Co., Casilla 1825, Lima, Peru.

Samuel I. Bowditch is now in the Philippines where he is assistant geologist on the staff of the Benguet Consolidated at Baguio.

Wallace E. Pratt was a recent visitor to New Haven and gave an informal talk before the graduate students of the Dept. of Geology, Yale University, on present and future trends of the application of geology to petroleum finding.

George B. Langford, chief geologist for McIntyre Porcupine Mines, Ltd., has been appointed Professor of Geology at the University of Toronto.

During the past two months, a series of lectures in geology has been given at Queen's University, the lecturers being: D. A. Nichols, T. L. Tanton, and F. T. Jolliffe, of the Geological Survey staff, and H. C. Horwood, of the Ontario Dept. of Mines.

J. B. Tyrrell has retired from the management of the Northern Canada Mining Corp. and the Kirkland Lake Gold Mining Co., but continues as president of both companies.

F. Blondel, chief mining engineer, Secretaire General, Comite d'Études Minieres pour la France d'Outre-Mer, Paris, has been elected president of the Societé Geologique de France.

E. S. Bastin, Professor of Geology at the University of Chicago, recently addressed the students and staff in the department of geology of the University of Toronto, on "The Genesis of the Mississippi Valley Lead and Zinc Ores."

J. E. Penberthy, consulting mining engineer for the Union Miniere du Haut Katanga, is spending several months in Tucson, Ariz.

John M. Boutwell was a recent visitor in New York and the east, and has now returned to his headquarters at Salt Lake City.

The *Annotated Bibliography* of Economic Geology is planning to publish next year a 10-volume index of annotations, in order to make the Bibliography more useful in running down references.

The joint meeting of the Society of Economic Geologists and the mining geology section of the American Institute of Mining and Metallurgical Engineers, held in New York Feb. 15–17, had the largest attendance of any of the different sections during the period of the meetings.

The *Mines Handbook* established in 1900 and published for years under the name of the *Copper Handbook* is to be continued under the name of *Mines Register*. The 1937 edition, containing over 2,000 pages, will be published by the Atlas Publishing Co., Inc., about the middle of the current year.

The Canadian Institute of Mining and Metallurgy is holding its 38th Annual Meeting at Montreal, March 15–17. A group of interesting papers on economic geology will be presented.

The Academy of Natural Sciences of Philadelphia, in celebration of its 125th anniversary, is arranging an International Symposium on Early Man to be held at the Academy on March 17–20.

The American Association of Petroleum Geologists will hold its 22nd Annual Meeting at Los Angeles March 17–19.